HUC 11010207 – Spring River
Water body IDs: 3203, 3980, and 5003
Pollutant(s): Metals (Cadmium, Lead, and Zinc)

Total Maximum Daily Load

for

Center Creek, Bens Branch, and Center Creek tributary

Jasper County

Impairments: Cadmium, Lead, and Zinc

Submitted: December 1, 2021
Approved: April 29, 2022

Prepared by: Water Protection Program, Watershed Protection Section

WATER BODY SUMMARY
Center Creek, Bens Branch, and Center Creek tributary

Water Body Identification Number (WBID) and Hydrologic Class:
WBID 3203 – Class P – Center Creek
WBID 3980 – Class C – Bens Branch
WBID 5003 – Class C – Center Creek tributary


Location of watershed in Missouri

Location: Near Joplin in Jasper County

8-digit Hydrologic Unit Code (HUC) Subbasin:[1]
11010207 – Spring River

10-digit HUC Watershed
1107020706 – Center Creek

Designated Uses:[2]
Irrigation
Industrial (WBID 3203 only)
Livestock and wildlife protection
Human health protection
Warm water habitat (aquatic life)
Cool water habitat (WBID 3203 only)
Whole body contact recreation category A (WBID 3203 only)
Whole body contact recreation category B (WBIDs 3980 and 5003 only)
Secondary contact recreation

Impaired Use:
Warm water habitat (aquatic life)

Pollutants Identified on the 2020 303(d) List:
WBID 3203 – Cadmium and Lead (sediment)
WBID 3980 – Cadmium, Lead, and Zinc (sediment); Cadmium and Zinc (water)
WBID 5003 – Cadmium, Lead, and Zinc (water)

Length and Location of Impaired Segment:
WBID 3203 – 26.8 miles from Section 14, T28N, R34W to Section 34, T28N, R31W
WBID 5003 - 2.7 miles from Mouth to Section 30, T29N, R32W
WBID 3980 - 5.8 miles from Mouth to Section 28, T28N, R32W

[1] Watersheds are delineated by the U.S. Geological Survey using a nationwide system based on surface hydrologic features. This system divides the country into 2,270 8-digit hydrologic units (USGS 2019). A hydrologic unit is a drainage area delineated to nest in a multilevel, hierarchical drainage system. A hydrologic unit code is the numerical identifier of a specific hydrologic unit consisting of a 2-digit sequence for each specific level within the delineation hierarchy (FGDC 2003).
[2] For designated uses see 10 CSR 20-7.031(1)(C) and 10 CSR 20-7.031 Table H. Presumed uses are assigned per 10 CSR 20-7.031(2)(A) and (B) and are reflected in the Missouri Use Designation Dataset described at 10 CSR 20-7.031(2)(E).

Table of Contents

List of Tables

List of Figures

List of Appendices

1. Introduction

In accordance with Section 303(d) of the federal Clean Water Act, the Missouri Department of Natural Resources is establishing total maximum daily loads (TMDLs) to address cadmium, zinc, and lead, which occur at concentrations that violate Missouri's water quality criteria in Center Creek, Center Creek tributary, and Bens Branch in Jasper County. This TMDL report addresses three water quality limited segments that were approved by the U.S. Environmental Protection Agency (EPA) for inclusion on Missouri's 2020 303(d) List of impaired waters on November 30, 2020.[3] Center Creek was listed in 2006 for cadmium in sediment and water, and lead in sediment from the Tri-State Mining District. This stream is now attaining water quality standards for cadmium in water and was removed from the 2020 303(d) List. Center Creek tributary was first listed in 2016 for cadmium and zinc in water from the Oronogo/Duenweg mining belt. This tributary has also been identified as impaired due to lead in water and this impairment was included on the 2020 303(d) List. Bens Branch was first listed in 2014 for cadmium, lead, and zinc in sediment, and was listed in 2016 for zinc in water from the Oronogo/Duenweg mining belt. In 2018, Bens Branch was listed for cadmium in water from mine tailings. This report addresses the impairments of Center Creek, Center Creek tributary, and Bens Branch by establishing TMDLs for cadmium, lead, and zinc.[4]

Section 303(d) of the federal Clean Water Act and Title 40 of the Code of Federal Regulations (CFR) Part 130 require states to develop TMDLs for waters that do not meet applicable water quality standards. Missouri's Water Quality Standards at Title 10 of the Code of State Regulation (CSR) Division 20 Chapter 7.031 consist of three major components: designated uses, water quality criteria to protect those uses, and an antidegradation policy. A TMDL is equal to the loading capacity of a water body for a specific pollutant and represents the maximum amount of a pollutant that a water body can assimilate and still attain and maintain water quality standards. The cadmium, lead, and zinc loading capacities for each water body are derived from the allowable concentrations established by Missouri's water quality criterion and are translated to mass load using stream flow under all recorded conditions. Once the loading capacity of a water body has been quantified, existing and future point sources and nonpoint sources are assessed for their potential to contribute pollutants in amounts that exceed the loading capacity. In accordance with 40 CFR 130.2, contributing point source facilities are given numeric wasteload allocations and nonpoint sources are given numeric load allocations. Per federal Clean Water Act section 303(d)(1)(C), a margin of safety must be included, which can be explicit (numeric) or implicit (qualitative), to account for any lack of knowledge concerning the relationship between pollutant loading and water quality, uncertainty associated with the model assumptions, and data inadequacies (40 CFR 130.7). The TMDLs for each pollutant consist of the wasteload allocation, the load allocation, and the margin of safety.

[3] A water quality limited segment is any segment where it is known that water quality does not meet applicable water quality standards, or is not expected to meet applicable water quality standards, even after the application of the technology-based effluent limitations required by sections 301(b) and 306 of the federal Clean Water Act (40 CFR 130.2).

[4] The Department maintains current and past 303(d) lists and corresponding assessment worksheets online at dnr.mo.gov/water/what-were-doing/water-planning/quality-standards-impaired-waters-total-maximum-daily-loads/impaired-waters.

2. Watershed Descriptions

Center Creek, Bens Branch, and Center Creek tributary are located in southwest Missouri within the Spring River subbasin, which is cataloged by the U.S. Geological Survey (USGS) as the 8-digit hydrologic unit code (HUC) 11010207. Within this subbasin, the Center Creek 10-digit HUC (1101020706) delineates the 300 square mile watershed that drains to the impaired water bodies. The upper portion of the Center Creek watershed consists of rolling hills with forest, pasture, and cropland. Developed land is more prevalent in the western portion of the watershed where the impaired water bodies are located, and includes the northern municipalities that comprise the greater Joplin area.

Center Creek originates in western Lawrence County, flows west for approximately 66 miles through Jasper County, then flows into Spring River at the Missouri and Kansas state line. The impaired segment of Center Creek extends from Spring River east through western Jasper County for 26.8 miles. The Missouri Use Designation Dataset (MUDD) identifies this segment of Center Creek as water body identification number (WBID) 3203.[5, 6] Center Creek tributary (WBID 5003) originates near the watershed boundary in Oronogo, flows south for 2.7 miles, and enters Center Creek approximately 9 miles upstream its confluence with Spring River. Bens Branch (WBID 3980) originates in Webb City, flows north between Webb City and Carterville for 5.8 miles, and enters Center Creek approximately 9.1 miles upstream of its confluence with Spring River. Figure 1 displays the locations of the impaired water body segments and the Center Creek watershed.

[5] The Missouri Use Designation Dataset documents the names and locations of the state's rivers, streams, lakes and reservoirs, which have been assigned designated uses (10 CSR 20-7031(1)(P)).

[6] Water body identification numbers (WBIDs) are unique to each water body or water body segment listed in the classification and use designation tables of 10 CSR 20-7.031 and delineated in the Missouri Use Designation Dataset.

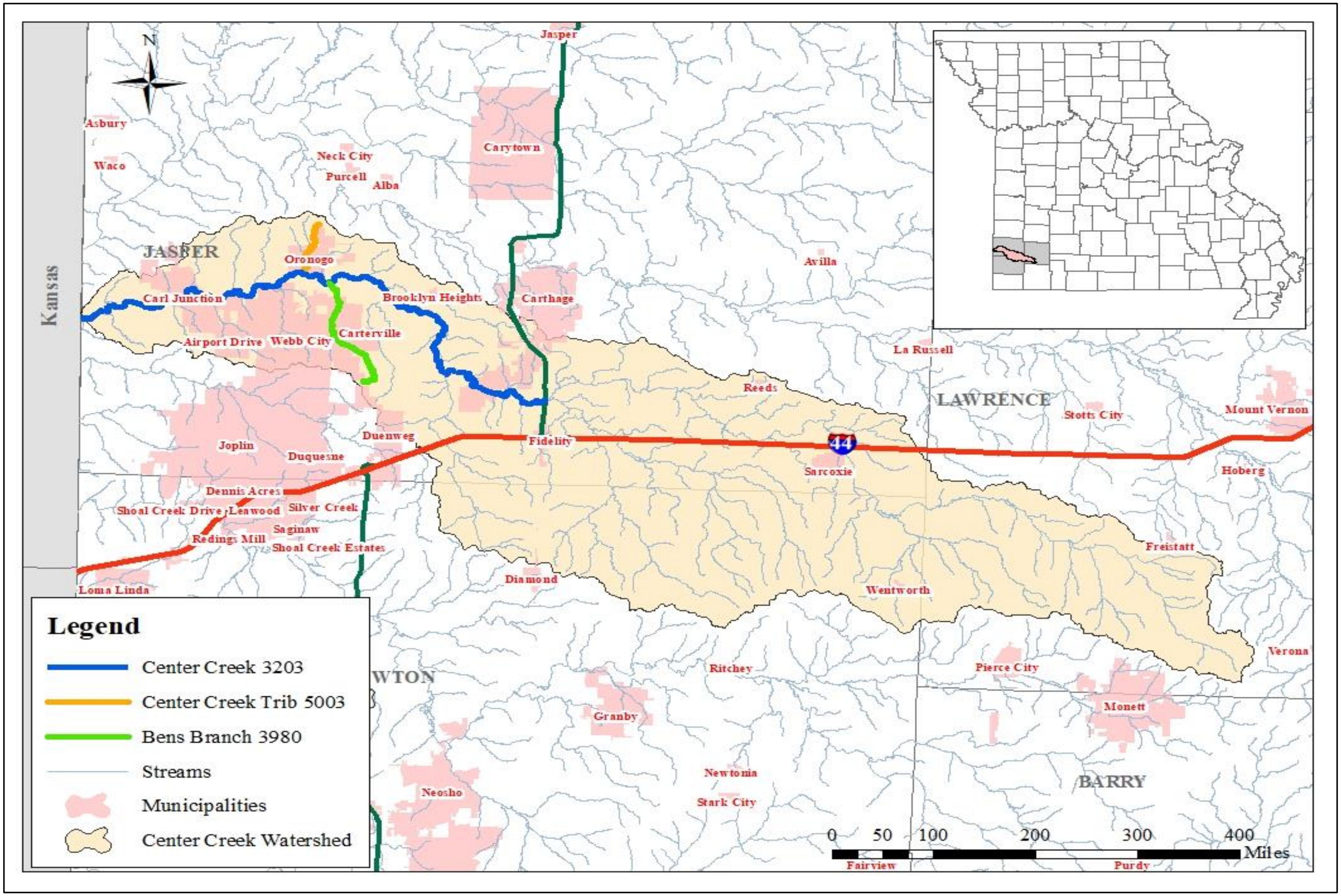

Figure 1. The Center Creek watershed.

2.1 Geology, Physiography, and Soils

The Center Creek watershed is located within the Neosho ecological drainage unit, which straddles portions of four states: southwestern Missouri, southeastern Kansas, northeastern Oklahoma, and northwestern Arkansas, including approximately 3,574 square miles of southwest Missouri. Ecological drainage units are groups of watersheds with similar biota, geography, and climate characteristics (USGS 2009). Streams within this drainage unit are typically clear with chert, gravel, and sand substrates and tend to have base flow supported by groundwater inputs, as springs are common in the region (MoRAP 2005). Geographic Information System (GIS) analysis of the Center Creek watershed identifies 20 unnamed springs, 11 named springs, approximately 6.32 miles of losing stream (including portions of the Center Creek and Bens Branch impaired segments), and 68 sinkhole features within the watershed.

The Center Creek watershed is located entirely in the Springfield Plateau Level IV ecoregion. Ecoregions are areas with similar ecosystems and environmental resources and are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. By recognizing spatial differences in ecosystems, ecoregions stratify the environment by its probable response to disturbance (Chapman et al. 2002). Ecoregions are further defined in Missouri's Water Quality Standards at 10 CSR 20-7.031(1)(H). The Springfield Plateau ecoregion is characterized by smooth to gently rolling plains and is less incised than other Ozark ecoregions. This ecoregion is a transitional zone between the Cherokee Plains and the woodlands of the Ozarks, consisting of tallgrass prairie, deciduous forest, and transitional savannah. The ecoregion has abundant karst features and rocky soils, commonly found in woodland areas. Predominant land cover consists of woodlands, pasturelands, and cleared prairies (Chapman et al. 2002).

The Springfield Plateau ecoregion is underlain by Mississippian-age cherty limestone. Mississippian limestone formed about 354 to 323 million years ago (the oldest rocks in the state). The breakdown of limestone in the Mississippian layers capped by Cherokee shales resulted in porous chert layers. Over time these layers were filled by hot, metal bearing materials originating from within the earth (Hambleton et al., 1959). This resulted in an abundance of minerals including: galena (PbS), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), pyrite/marcasite (FeS_2), calcite ($CaCO_3$), dolomite ($Ca,Mg(CO_3)_2$), and quartz (SiO_2). Galena and sphalerite are commercially important, because they are the minerals from which cadmium, lead, and zinc are derived. These two minerals are found in association and are mined together, with cadmium commonly found in sphalerite mineral deposits (Schwartz, 2000). Center Creek, Center Creek tributary, and Bens Branch watersheds are located in the historic Tri-State Mining District and the Oronogo-Duenweg Mining Belt. The Tri-State Mining District covers approximately 2,500 square miles in southwest Missouri, northeast Oklahoma, and southeast Kansas. Commercial demand for cadmium, lead, and zinc resulted in prolific mining operations in the region beginning in the 1830s, with the closure of the last mining operations occurring in the late 1960s (USEPA, 2017).

The Center Creek watershed is comprised of approximately 67 individual soil types. Although soils in the watershed are varied, they can be categorized based on similar runoff potentials into hydrologic soil groups. A hydrologic soil group indicates the rate at which water enters the soil profile under conditions of a bare, thoroughly wetted soil surface, which in turn may affect the potential amount of water entering the stream as runoff (NRCS 2009). Table 1 provides a summary of the hydrologic soil groups in the Center Creek watershed and Figure 2 shows their distribution. Group A represents soils with the highest rate of infiltration and the lowest runoff potential. Group D represents the group with the lowest rate of infiltration and highest runoff potential. Many wet

soils fall in to dual soil groups (e.g., Group C/D) due to the presence of a high water table saturating the surface. Dual hydrologic soil groups account for this condition by providing both the drained and undrained condition of the soil.[7] Areas of the Center Creek watershed where soils were not rated are described by the U.S. Department of Agriculture's Web Soil Survey as being open water or mine waste sites.[8] It should be noted that hydrologic soil groups are only one factor that determines the volume of runoff in the watershed. Impervious surfaces, vegetative cover, slope, rainfall intensity, and land use can significantly influence the potential for runoff regardless of the characteristics of the underlying soil.

Table 1. Hydrologic soil groups in the Center Creek watershed (NRCS 2011).

Hydrologic Soil Group	Center Creek Watershed Area		
	mi^2	km^2	%
Group A	33.93	87.88	11.31
Group B	70.02	181.34	23.34
Group C	80.50	20.48	26.84
Dual Group C/D	49.08	127.12	16.36
Group D	59.92	155.20	19.98
Not Rated	6.51	16.58	2.17
Totals =	299.95	766.88	100.00

[7] For the purpose of hydrologic soil groups, adequately drained means that the seasonal high water table is kept at least 24 inches below the surface in a soil where it would be higher in a natural state (NRCS 2009).

[8] https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

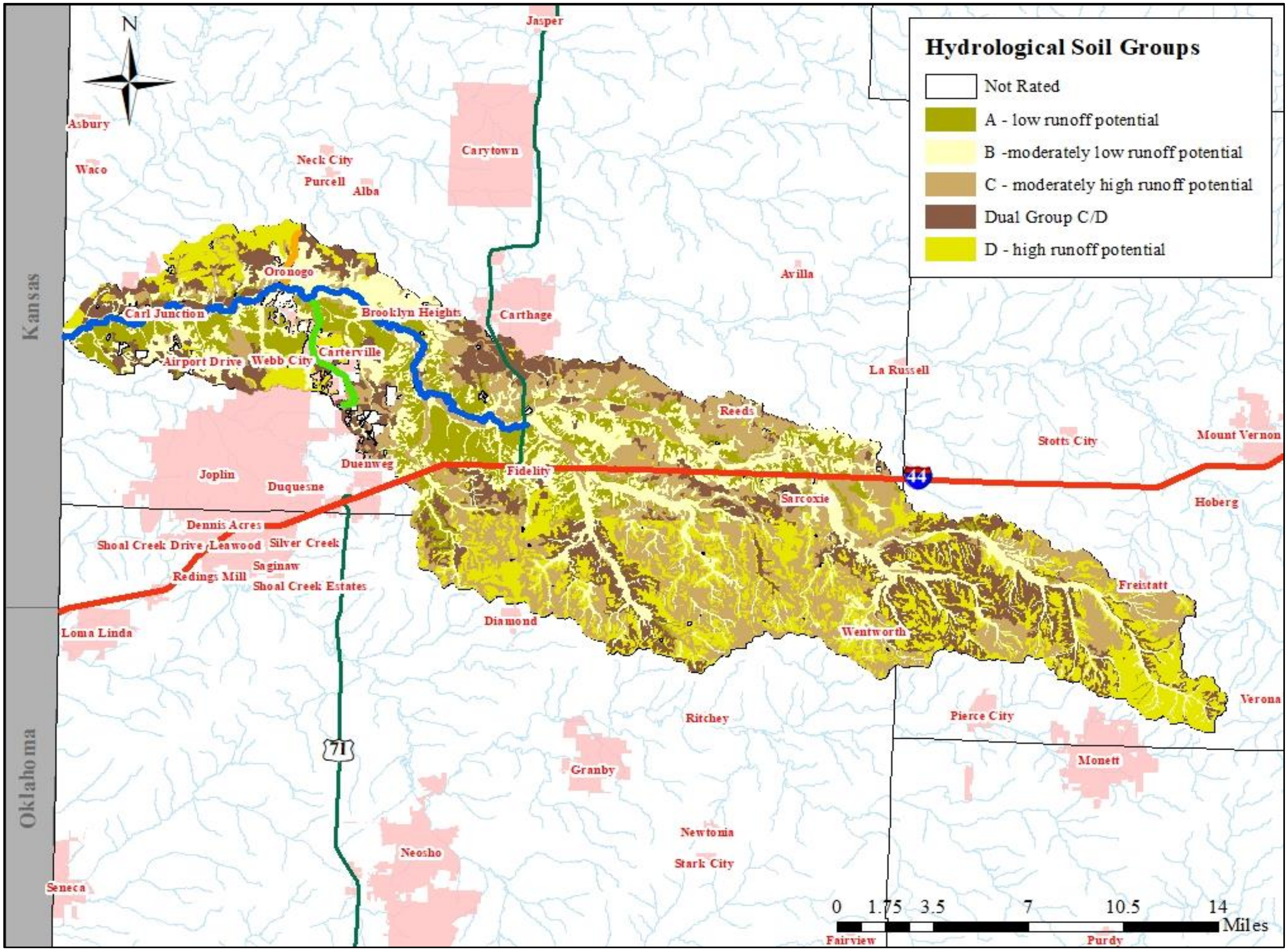

Figure 2. Hydrological soil groups in the Center Creek watershed.

2.2 Climate

The most recent climate data from a weather station in close proximity to the Center Creek watershed were measured at the National Weather Service's Joplin Regional Airport Weather Station in Jasper County. The climate normals were developed based on temperature and precipitation data collected at that station between 1981 and 2010 (NOAA 2010). Precipitation normals are especially important because they relate to stream flow and runoff events that influence pollutant loading. Table 2 presents the 30-year monthly climate normals from the Joplin Regional Airport Weather Station for both temperature (Temp) and precipitation (PPTN). Figures 3 and 4 further summarize these data.

Table 2. 30-year monthly climate normals at the Joplin Regional Airport Weather Station.

Month	Total PPTN Normal		Mean Max Temp		Mean Min Temp	
	in	mm	ºF	ºC	ºF	ºC
January	2.03	51.56	44.9	7.2	25	-3.9
February	2.32	58.93	50.5	10.3	29.2	-1.6
March	3.42	86.87	60.1	15.6	37.7	3.2
April	4.47	113.54	70	21.1	46.9	8.3
May	5.71	145.03	77.7	25.4	56.2	13.4
June	5.86	148.84	85.8	29.9	65.1	18.4
July	3.81	96.77	90.6	32.6	69.9	21.1
August	3.35	85.09	91	32.8	68.4	20.2
September	4.95	125.73	82.3	27.9	59.3	15.2
October	4.03	102.36	71.3	21.8	48.3	9.1
November	3.78	96.01	58.9	14.9	37.9	3.3
December	2.82	71.63	47	8.3	27.5	-2.5
	Total		**Average**		**Average**	
	46.55	1,182.37	69.2	20.7	47.6	8.7

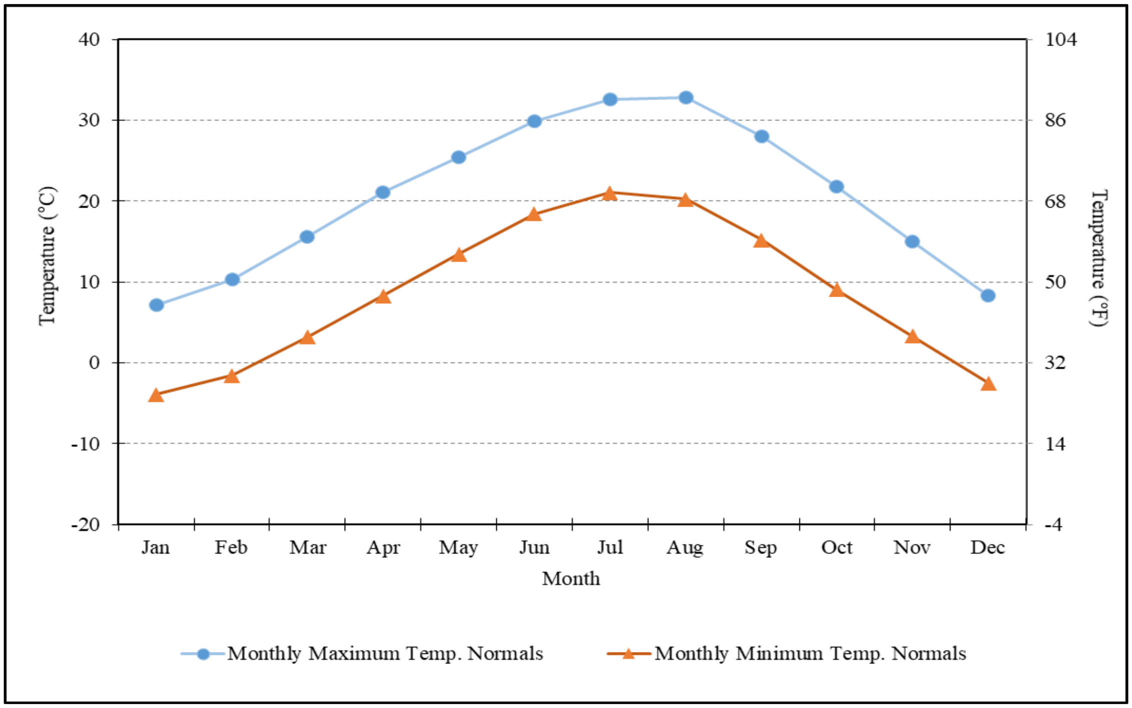

Figure 3. Monthly minimum and maximum temperature normals – Joplin Regional Airport Weather Station.

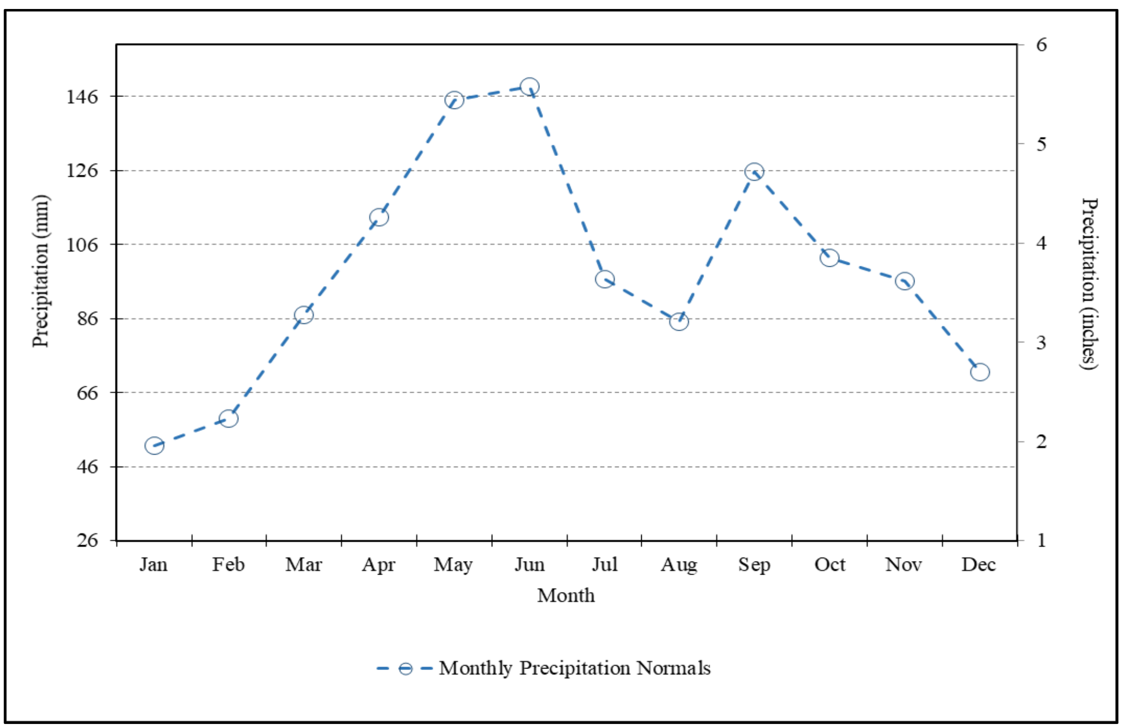

Figure 4. Monthly precipitation normals – Joplin Regional Airport Weather Station.

2.3 Population

State and county population estimates are available from the U.S. Census Bureau's 2010 census and can be localized using census block data (U.S. Census Bureau 2010). Population estimates for the Center Creek watershed were derived using GIS software by overlaying the watershed boundaries over a map of census blocks (Figure 5). Wherever the centroid of a census block fell within a watershed boundary, the entire population of the census block was included in the total. If the centroid of the census block was outside the boundary, the population of the entire block was excluded. The municipal population was estimated using a similar method whereby municipal areas where overlain on the map of census blocks. The rural population was calculated as the difference between the municipal population and the total population. As shown in Table 3, the population in the Center Creek watershed has increased since 1990. As of the 2010 census, the U.S. Census Bureau has classified portions of the watershed as being an "urban area." Urban area designation is one criterion used for determining if a municipality is subject to small municipal separate storm sewer system (MS4) permit regulations. Currently portions of the greater Joplin are subject to such regulations.

Table 3. Population estimates for the Center Creek watershed.

Watershed	Missouri Population Data								
	Municipal			Rural			Total		
	1990	2000	2010	1990	2000	2010	1990	2000	2010
Center Creek Watershed	17,078	20,691	25,777	9,688	12,794	14,618	26,766	33,485	40,395

EPA completed a demographic analysis in 2014 to identify areas where environmental justice may be of concern. EPA used demographic information from census block data on a 12-digit HUC scale and a web-based tool called EJSCREEN to determine areas that have potential environmental justice concerns. EPA defines environmental justice as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (USEPA 2014a). Communities determined to have environmental justice concerns may qualify for financial and strategic assistance for addressing environmental and public health issues. The EPA analysis determined that three of the 12-digit HUC watersheds comprising the Center Creek watershed have potential Environmental Justice concerns. Table 4 provides percent coverage of environmental justice concerns for these 12-digit HUC subwatershed within the Center Creek watershed.

Table 4. 12-Digit HUCs with Environmental Justice Concerns.

12 Digit HUC	Percent of HUC cover by potential EJ block groups
110702070602	5-15 %
110702070605	5-15 %
110702070607	15-30%

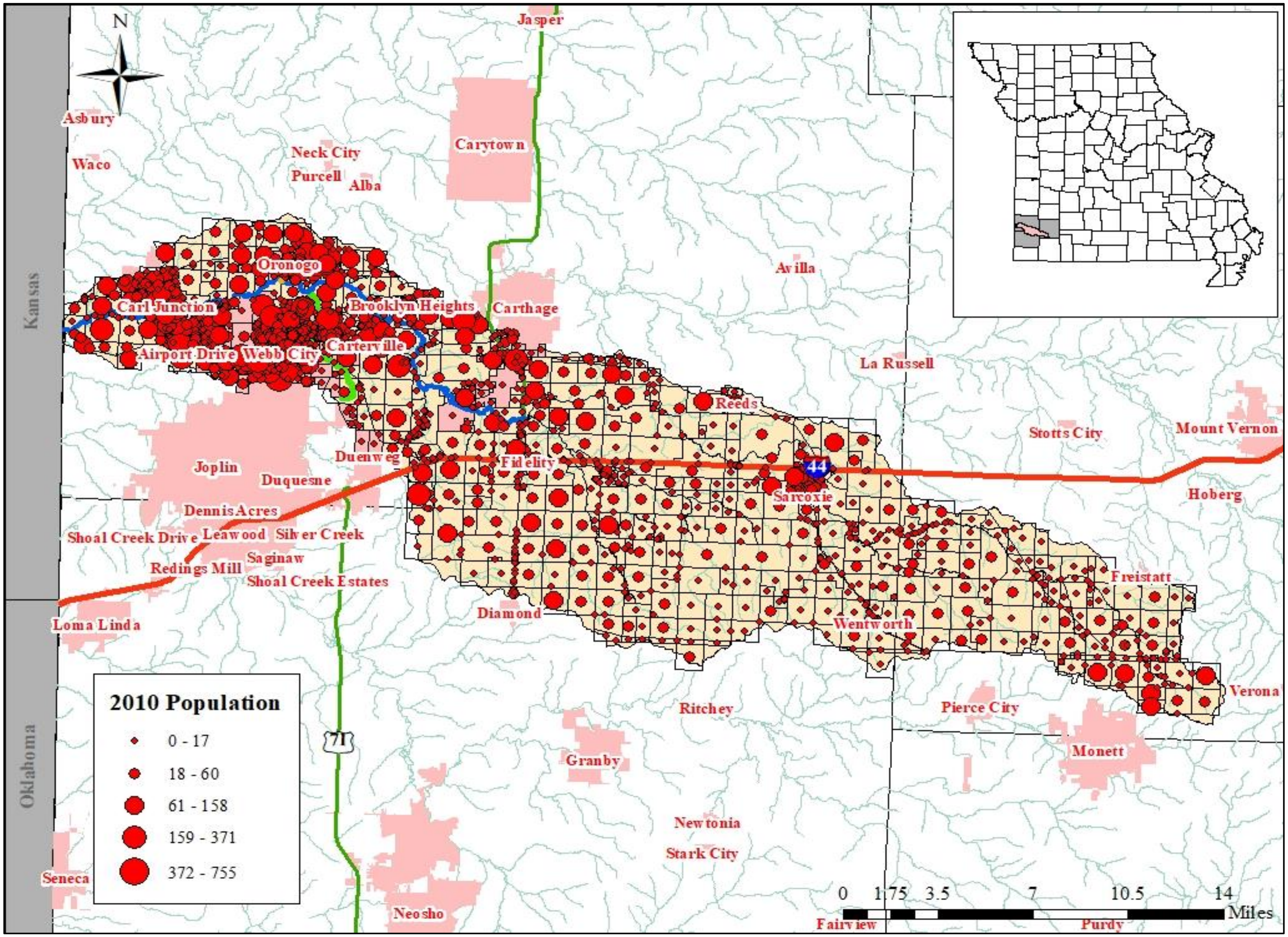

Figure 5. Census block populations in the Center Creek watershed.

2.4 Land Cover

A land cover analysis was completed using the 2011 National Land Cover Database published by USGS (Homer et al. 2015). Land cover information for the Center Creek watershed is summarized in Table 5. Figure 6 depicts the distribution of land cover throughout the watershed. It should be noted that barren lands in the Center Creek watershed are associated with mining activities or remediation sites, which are the primary contributors of metals to the impaired streams.

Table 5. Land cover in the Center Creek watershed.

Land Cover Type	Center Creek		Center Creek tributary		Bens Branch	
	Area mi^2 (km^2)	Percent (%)	Area mi^2 (km^2)	Percent (%)	Area mi^2 (km^2)	Percent (%)
Developed, High Intensity	0.91 (2.35)	0.30	0.005 (0.13)	0.17	0.12 (0.31)	1.92
Developed, Medium Intensity	2.28 (7.46)	0.96	0.047 (0.121)	1.56	0.42 (1.09)	6.64
Developed, Low Intensity	8.66 (22.44)	2.89	0.198 (0.513)	6.62	0.12 (0.31)	15.36
Developed, Open Space	16.97 (43.96)	5.66	0.289 (0.749)	9.68	0.43 (1.12)	6.84
Barren Land	4.07 (10.55)	1.36	0.063 (0.163)	2.11	1.67 (4.33)	26.42
Cultivated Crops	14.33 (37.12)	4.78	0.269 (0.697)	9.01	0.02 (0.04)	0.27
Grassland and Pasture	174.75 (452.61)	58.26	1.709 (4.426)	57.19	1.31 (3.40)	20.73
Herbaceous	1.52 (3.95)	0.51	0.008 (0.021)	0.27	0.05 (0.12)	0.74
Deciduous Forest	68.61 (177.70)	4.78	0.316 (0.819)	10.59	1.16 (3.00)	18.30
Shrub and Scrub	1.66 (4.30)	0.55	N/A	N/A	0.11 (0.27)	1.67
Mixed Forest	0.07 (0.19)	0.02	N/A	N/A	N/A	N/A
Evergreen Forest	0.48 (1.24)	0.16	0.002 (0.004)	0.05	N/A	N/A
Emergent Herbaceous Wetland	0.14 (0.37)	0.05	N/A	N/A	N/A	N/A
Woody Wetlands	4.28 (11.09)	1.43	0.027 (0.070)	0.90	0.05 (0.12)	0.73
Open Water	0.60 (1.55)	0.20	0.036 (0.094)	1.22	0.03 (0.07)	0.40
Totals	299.95 (776.88)	100.00	2.99 (7.74)	100.00	6.34 (16.41)	100.00

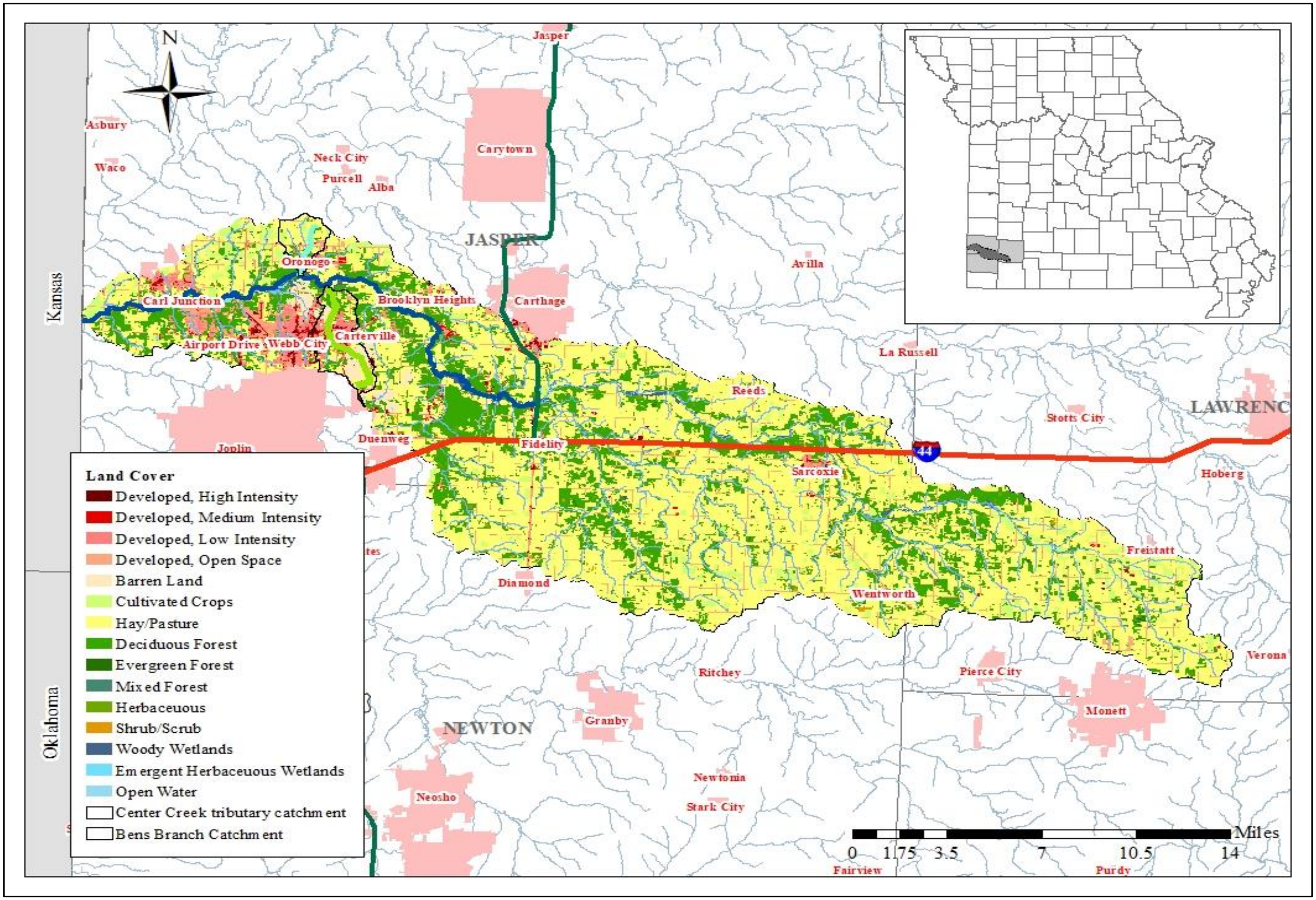

Figure 6. Land cover in the Center Creek watershed.

3. Applicable Water Quality Standards

TMDLs identify the maximum pollutant load that a water body can assimilate and still attain and maintain water quality standards. Water quality standards are therefore central to the TMDL development process. Under the federal Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters (U.S. Code Title 33, Chapter 26, Subchapter III). Water quality standards consist of three major components: designated uses, water quality criteria, and an antidegradation policy. In accordance with federal regulations at 40 CFR 131.10, Missouri's Water Quality Standards for each individual water body also provide for the attainment and maintenance of water quality in any downstream waters. Revising existing water quality standards is not within the purview of TMDL development. If future water quality monitoring demonstrates that existing water quality standards are not protective of individual water bodies or downstream uses, new water quality standards can be proposed in accordance with the guidance provided in EPA's Water Quality Standards Handbook.[9]

3.1 Designated Uses

Missouri's Water Quality Standards at 10 CSR 20-7.031(1)(C) defines designated uses that are assigned to individual water bodies in accordance with 10 CSR 20-7.031(2) and are listed in 10 CSR 20-7.031, Table G (Lakes) and Table H (Streams). Missouri's Water Quality Standards designate the following uses of Center Creek, Center Creek Tributary, and Bens Branch:

- Irrigation;
- Industrial (WBID 3203 only);
- Livestock and wildlife protection;
- Human health protection;
- Warm water habitat (aquatic life);
- Cool water habitat (WBID 3203 only);
- Whole body contact recreation category A (WBID 3203 only);
- Whole body contact recreation category B (WBIDs 5003 and 3980 only); and
- Secondary contact recreation.

The warm water habitat (aquatic life) designated uses assigned to Center Creek, Center Creek Tributary, and Bens Branch are impaired due to high cadmium, lead, and zinc concentrations in sediment or dissolved in the water column.[10]

3.2 Water Quality Criteria

Water quality criteria represent a level of water quality that supports and protects particular designated uses. Water quality criteria are expressed as specific numeric criteria and as general narrative statements. Missouri's Water Quality Standards (10 CSR 20-7.031(4) and (5)) establish general criteria applicable to all waters of the state at all times and numeric criteria applicable to waters contained in 10 CSR 20-7.031, Tables G and H.

---

[9] https://www.epa.gov/wqs-tech/water-quality-standards-handbook

[10] Although Center Creek is also assigned the Cool Water Habitat use, Missouri's hardness-based metals criteria are associated with protection of the Warm Water Habitat designated use.

3.2.1 General Criteria and Assessment Methods

Concentrations of metals in benthic stream sediments in sufficient amounts that result in toxicity to aquatic life or that harm benthic organisms violate the general criteria of Missouri's Water Quality Standards at 10 CSR 20-7.031(4)(D) and (5)(B)1. Per 10 CSR 20-7.031(4)(D), "waters shall be free from substances or conditions in sufficient amounts to result in toxicity to human, animal, or aquatic life" and per 10 CSR 20-7.031(5)(B)1, "…Concentrations of these substances in bottom sediments… shall not harm benthic organisms…."

The Department determines sediment metal toxicity by calculating the geometric mean of sediment metal concentrations from an adequate number of samples. The resulting value is compared to a corresponding Probable Effect Concentration (PEC) as defined in MacDonald et al., 2000. PEC values represent pollutant levels at which harmful effects to aquatic communities will likely be observed. The Department determines that benthic sediments are impaired for dissolved metals if the geometric mean of the observed values is greater than 150 percent of the applicable PEC value. This accounts for variability in dissolved metals concentrations that results from continuous dissolution and precipitation of metals into and out of the sediment pore water. In order to assess the synergetic impacts of multiple metals in the sediment pore water, the Department applies the PEC Quotient (PECQ). The PECQ represents a ratio value of the geometric mean of metal concentrations over the associated metal's PEC value. PECQ values over a ratio of 0.5 are considered to represent conditions that are harmful to warm water aquatic species. The Department determines that sediment toxicity will likely be harmful to aquatic communities due to synergetic impacts if the PECQ value exceeds 0.75 (MacDonald et al., 2000).

Bens Branch and Center Creek tributary flow to Center Creek, which flows into the Spring River (WBID 3159), which then flows into neighboring Kansas. General criteria at 10 CSR 20-7.031(4)(E) also apply such that, "Waters shall maintain a level of water quality at their confluences to downstream waters that provides for the attainment and maintenance of the water quality standards of those downstream waters, including waters of another state." TMDL target concentrations (Section 7) will therefore be protective of aquatic life in the Spring River. Additional flows and dilution resulting from the much larger Spring River will provide additional reductions in pollutant concentrations originating from Center Creek. The Department also consulted with Kansas Department of Health and Environment (KDHE) to ensure selected TMDL targets will be protective of downstream aquatic life uses in Kansas.[11]

3.2.2 Numeric Criteria and Assessment Methods

Missouri's Water Quality Standards establish numeric criteria for cadmium, lead, and zinc based on acute toxicity and chronic toxicity. Per 10 CSR 20-7.031(1)(A), acute toxicity is defined as, "Conditions producing adverse effects or lethality on aquatic life following short-term exposure. The acute criteria in Tables A1, A2, and B1 are maximum concentrations which protect against acutely toxic conditions." Per 10 CSR 20-7.031(1)(E), chronic toxicity is defined as, "Conditions producing adverse effects on aquatic life or wildlife following long-term exposure but having no

[11] In addition to notifying KDHE of the public comment period for this TMDL, the Department met virtually with KDHE on November 8, 2021 and again via telephone on November 16, 2021. In both instances KDHE noted TMDL targets for Center Creek are protective of aquatic life in Kansas and expressed no concern on the adequacy of this TMDL.

readily observable effect over a short time period. Chronic numeric criteria in Tables A1, A2, B2, and B3 are maximum concentrations which protect against chronic toxicity; these values shall be considered four- (4-) day averages, with the exception of total ammonia as nitrogen which shall be considered a thirty- (30-) day average."

Missouri's Water Quality Standards at 10 CSR 20-7.031(5)(B)1 specifies that the numeric criteria found in Tables A1, A2, B2, and B3 of the Water Quality Standards shall not be exceeded, and that with the exception of mercury, all metals should be analyzed as dissolved metals. Table A1 of Missouri's Water Quality Standards establish acute and chronic numeric criteria for metals for aquatic life protection. Table A1 refers to Table A2 for both acute and chronic numeric criteria for cadmium, lead, and zinc. Table A2 displays metals criteria equations which are hardness dependent, with hardness as the only equation variable.[12] Table 6 displays the metals criteria for aquatic life protection, as found in Table A2 of the Water Quality Standards. The criteria displayed in Table 6 are applied directly to each dissolved metal to determine whether the acute and chronic toxicity are exceeded in the stream water.

Table 6. Dissolved metals criteria for the protection of aquatic life.

Dissolved Metal	Criterion Type	Criterion Formula
Cadmium (µg/L)	Acute	$e^{(1.0166*\ln(\text{Hardness}) - 3.062490)} * (1.136672 - (\ln(\text{Hardness})*0.041838))$
	Chronic	$e^{(0.7977*\ln(\text{Hardness}) - 3.909)} * (1.101672 - (\ln(\text{Hardness})*0.041838))$
Lead (µg/L)	Acute	$e^{(1.273*\ln(\text{Hardness}) - 1.460448)} * (1.46203 - (\ln(\text{Hardness})*0.145712))$
	Chronic	$e^{(1.273*\ln(\text{Hardness}) - 4.704797)} * (1.46203 - (\ln(\text{Hardness})*0.145712))$
Zinc (µg/L)	Acute & Chronic	$e^{(0.8473*\ln(\text{Hardness}) + 0.884)} * 0.98$

3.3 Antidegradation Policy

Missouri's Water Quality Standards include the EPA "three-tiered" approach to antidegradation and may be found at 10 CSR 20-7.031(3).

Tier 1 – Protects public health, existing instream water uses, and a level of water quality necessary to maintain and protect existing uses. Tier 1 provides the absolute floor of water quality for all waters of the United States. Existing instream water uses are those uses that were attained on or after November 28, 1975, the date of EPA's first water quality standards regulations related to existing uses.

Tier 2 – Protects and maintains the existing level of water quality where it is better than applicable water quality criteria. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: (1) a finding that it is necessary to accommodate important economic and social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions;

[12] In accordance with 10 CSR 20-7.031(1)(CC), water hardness is the total concentration of calcium and magnesium ions expressed as calcium carbonate. Hardness is calculated as the median value of a representative number of samples from water in question or similar waters within the same ecoregion at appropriate flow conditions.

and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing uses.

Tier 3 – Protects the quality of outstanding national and state resource waters, such as waters of national and state parks, wildlife refuges, and waters of exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality.

Waters in which a pollutant is at, near, or exceeds the water quality criteria are considered in Tier 1 status for that pollutant. Therefore, the antidegradation goals for Center Creek, Bens Branch, and Center Creek tributary are to restore water quality to levels that meet the water quality standards.

4. Defining the Problem

As discussed in Section 2.1, prolific mining operations were present in the Tri-State Mining District and the Oronogo-Duenweg Mining Belt between the 1830s and the late 1960s. Now fifty years after mining operations ceased, mine-waste piles, groundwater discharges from underground mines, and widespread exposure of mineral-laden limestone continue to be sources of cadmium, lead, and zinc loading in the Center Creek watershed. The sources of metals contamination of the water in the streams is a mixture of surface runoff of water through mine tailings scattered throughout the watershed and re-emergence of groundwater from flooded mines. Heavy metal contamination of sediments is a result of surface runoff and the movement of contaminated sediments from mining areas.

In accordance with Missouri's 2020 Listing Methodology Document, which further describes the assessment methods discussed in Sections 3.2.1 and 3.2.2 of this report, the warm water habitat (aquatic life) designated uses for Center Creek, Bens Branch, and Center Creek tributary are impaired for metals toxicity as displayed in Table 7. Sufficient data are available to support these listings as summarized in Tables 8-11. As discussed in Section 3, Missouri does not have specific numeric metals criteria for sediment toxicity and sediment impairments are based on 150 percent exceedance of PEC values.

Individual metals measurements for each water body and hardness data for Center Creek are provided in Appendix A. Figures displaying the assessment data and illustrating the nature of the impairments are provided in Appendix B. The individual measurements and assessment data were not used to calculate loading capacities, wasteload allocations, or load allocations. The data may be used to estimate pollutant reduction targets, to target implementation activities, and to select appropriate best management practices. Reduction targets for Center Creek, Bens Branch, and Center Creek tributary are presented in a supplemental TMDL implementation strategies document available online at dnr.mo.gov/water/what-were-doing/water-planning/quality-standards-impaired-waters-total-maximum-daily-loads/tmdls.

Table 7. Summary of Metal Impairments in the Center Creek Watershed

Water Body	Water Body ID	Pollutant	Initial Listing Year	Source
Center Creek	3203	Cadmium (water)[13] Cadmium (sediment) Lead (sediment)	2006 2006 2006	Tri-State Mining District
Center Creek Tributary	5003	Cadmium (water) Lead (water) Zinc (water)	2016 2020 2016	Oronogo-Duenweg Mining Belt and mine tailings
Bens Branch	3980	Cadmium (sediment) Lead (sediment) Zinc (sediment)	2014 2014 2014	Oronogo-Duenweg Mining Belt
		Cadmium (water) Lead (water)	2018 2016	

Table 8. Assessment summary for sediment metals in Center Cr. WBID 3203.[14]

Parameter	Data Range	Number of Samples	Geometric Mean (mg/kg)	PEC (mg/kg)	150% PEC (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Cadmium (sediment)	1995-2015	33	19.66	4.98	7.47	1.45	89.20
Lead (sediment)	1995-2015	33	202.45	128.00	192.00	20.00	834.00

Table 9. Assessment summary for dissolved metals in Center Creek Tributary WBID 5003.

Parameter	Year	Number of Samples	Geometric Mean (μg/l)	Minimum (μg/l)	Maximum (μg/l)	Criteria	No. of Acute Exceedances	No. of Chronic Exceedances
Cadmium (dissolved)	2011	2	1.90	0.34	10.60		1	1
	2012	3	14.08	9.59	18.20	Acute	3	0
	2013	2	9.27	4.77	18.00	8.07μg/l	1	1
	2014	4	6.78	3.57	17.60		1	3
	2015	3	5.52	3.61	7.11	Chronic	0	3
	2016	3	11.91	10.30	14.40	1.08 μg/l	3	0
	2017	2	17.44	15.20	20.00		2	0
Lead (dissolved)	2011	2	1.33	1.16	1.53		0	0
	2012	3	3.19	0.90	6.24	Acute	0	0
	2013	2	1.22	0.50	3.00	115.89 μg/l	0	0
	2014	4	0.86	0.50	2.33		0	0
	2015	3	0.95	0.50	1.74	Chronic	0	0
	2016	3	8.04	6.41	9.15	4.52 μg/l	0	2
	2017	2	10.73	8.35	13.80		0	1
Zinc (dissolved)	2011	2	1,652.73	776.00	3,520.00	Acute	2	2
	2012	3	4,169.71	3,560.00	5,610.00	185.91 μg/l	3	3
	2013	2	3,595.97	3,350.00	3,860.00		2	2
	2014	4	3,976.75	3,500.00	4,460.00	Chronic	4	4
	2015	3	2,380.04	1,940.00	3,390.00	185.91 μg/l	3	3

[13] Center Creek is attaining water quality standards associated with cadmium in water (dissolved) and this impairment has been removed from the 2020 303(d) List. However, TMDL targets to address the cadmium in sediment impairment through translation to pore water using the equilibrium partitioning method are based on the dissolved metals criteria.
[14] Sediment samples are sieved to 2 millimeter prior to laboratory analysis

	2016	3	2,195.41	1,820.00	2,550.00		3	3
	2017	2	2,919.98	2,930.00	2,910.00		2	2

Table 10. Assessment summary for dissolved metals - Bens Branch WBID 3980

Parameter	Year	Number of Samples	Geometric Mean (µg/l)	Minimum (µg/l)	Maximum (µg/l)	Criteria	No. of Acute Exceedances	No. of Chronic Exceedances
Cadmium (dissolved)	2011	2	3.61	0.87	15.00	Acute 8.07µg/l Chronic 1.08 µg/l	1	0
	2012	3	3.99	0.51	16.00		1	1
	2013	2	2.22	0.37	13.30		1	0
	2014	4	0.45	0.12	2.53		0	1
	2015	6	0.38	0.10	5.09		0	2
	2016	4	1.42	0.14	5.62		0	2
	2017	2	2.32	1.06	5.09		0	1
Zinc (dissolved)	2011	2	2,100.60	1,250.00	3,530.00	Acute 185.91 µg/l Chronic 185.91 µg/l	2	2
	2012	3	1,715.16	680.00	3,500.00		3	3
	2013	2	1,154.49	766.00	1,740.00		2	2
	2014	4	939.76	572.00	2,110.00		4	4
	2015	6	32.44	0.57	2,380.00		3	3
	2016	4	262.97	0.76	2,320.00		3	3
	2017	2	1,405.07	833.00	2,370.00		2	2

Table 11. Assessment summary of sediment data for Bens Branch WBID 3980.

Water Body	Parameter	Data Range	Number of Samples	Geometric Mean (mg/kg)	PEC (mg/kg)	150% PEC (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Bens Branch WBID 3980	Cadmium (sediment)	1991-2007	3	84.46	4.98	7.47	16.3	376
	Lead (sediment)	1976-2007	8	751.45	128	192	285	2,271
	Zinc (sediment)	1976-2007	8	5,893.49	459	688.5	2,210	24,673

5. Source Inventory and Assessment

Point (regulated) and nonpoint (unregulated) sources may contribute metal loads to the impaired water bodies. However, the relative significance of each source‘s loading may vary. The following source inventory and assessment identifies and characterizes known, suspected, and potential sources of cadmium, lead, and zinc loading within the Center Creek watershed. Potential sources of metals loading are categorized and quantified to the extent that information is available.

5.1 Point Sources

Point sources are defined under Section 502(14) of the federal Clean Water Act and are regulated under the National Pollutant Discharge Elimination System through the Missouri State Operating Permit program.[15] A point source is defined as any discernible, confined, and discrete conveyance,

[15] The Missouri State Operating Permit program is Missouri's program for administering the federal National Pollutant Discharge Elimination System (NPDES). NPDES requires all point sources that discharge pollutants to waters of the United States to obtain a permit. Issued and proposed operating permits are available online at dnr.mo.gov/water/business-industry-other-entities/permits-certification-engineering-fees.

such as a pipe, ditch, channel, tunnel, or conduit, by which pollutants are transported to a water body. Point sources include domestic wastewater treatment facilities, industrial and commercial facilities including landfills, concentrated animal feeding operations (CAFOs), MS4s, and stormwater discharges from industrial areas and construction sites. Illicit straight pipe discharges are also point sources but are illegal and therefore unpermitted. Additionally, a memo issued by EPA Water Management Division Director Max Dodson on December 22, 1993, states that historical mining areas are point sources and should therefore be regulated through permits. The locations of primary permitted outfalls in the Center Creek watershed are presented in Figure 7. Some facilities have multiple permitted outfalls within the watershed.

As of October 9, 2020, the Center Creek watershed contains 14 site-specific permitted facilities. These facilities include: 12 domestic wastewater treatment facilities, and two industrial and commercial facilities. Additional permitted features found in the Center Creek watershed include five general CAFO permits and 69 general wastewater or general stormwater permits, which are identifiable by their permit numbers having the prefix “MO-G” or “MO-R,” respectively. Only general land disturbance and stormwater permits are located within the subwatersheds of Bens Branch (six permits) and Center Creek tributary (two permits).

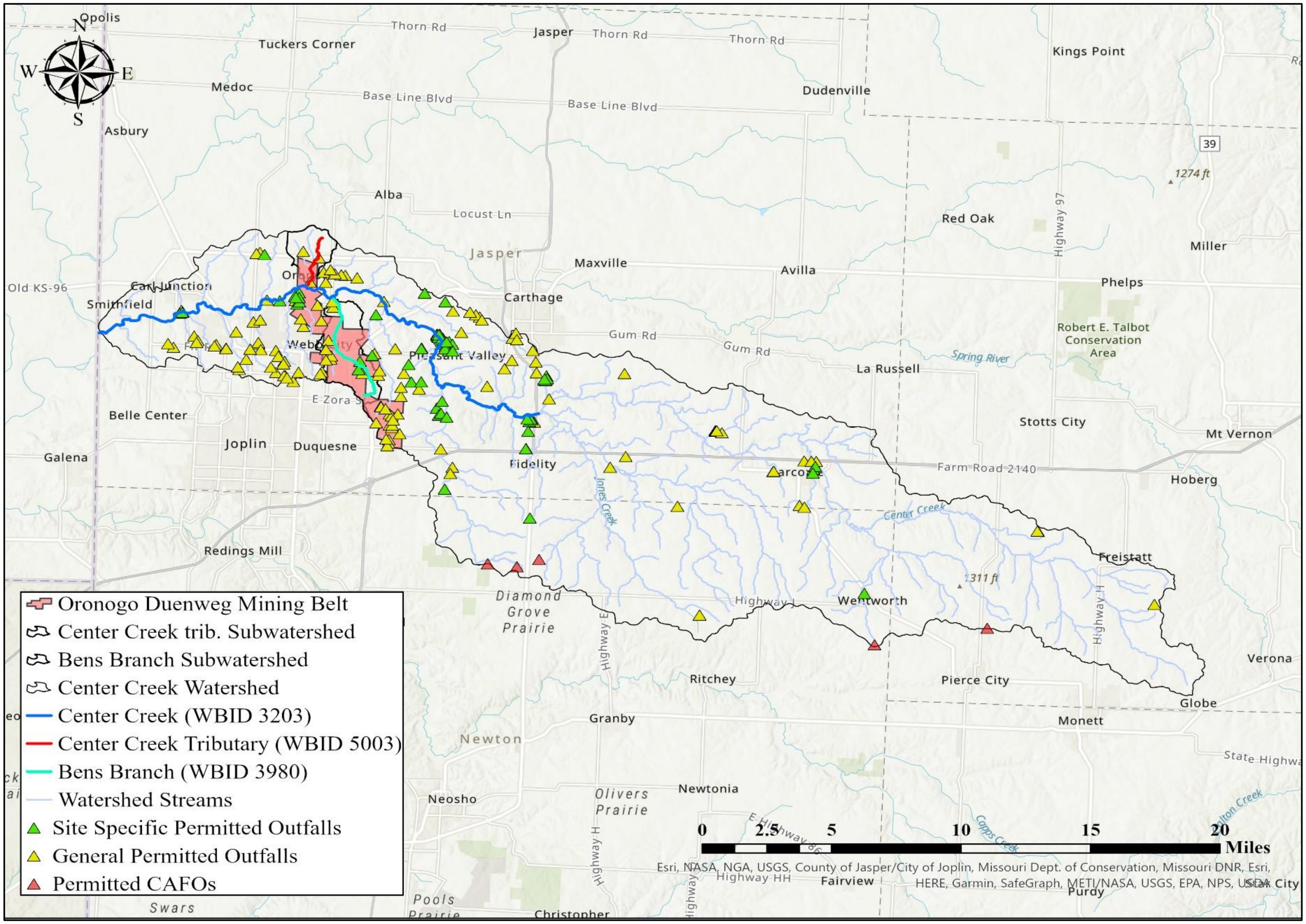

Figure 7. Permitted outfalls and Oronogo-Duenweg Mining Belt in the Center Creek watershed[16]

[16] Due to limitations in available GIS data, individual outfalls associated with municipal separate stormwater sewer systems are not presented. Although not currently permitted, mining areas associated with the Oronogo-Duenweg Mining Belt are considered as point sources for this TMDL and are presented for reference.

5.1.1 Domestic Wastewater Treatment Facilities

Dischargers of domestic wastewater include both publicly owned (e.g., municipal, public sewer district, etc.) and private treatment facilities. Domestic wastewater is primarily household waste, including graywater and sewage. Generally, domestic wastewater is not expected to contain significant concentrations of metals, unless the influent or source waters inherently have high metal concentrations. Certain wastewater discharges to municipal facilities may contain high concentrations of metals associated with industrial production processes (Barrak, 2011), however, industrial pretreatment programs can reduce such pollutants prior to discharge to publicly owned treatment facilities. Missouri pretreatment regulations are found in 10 CSR 20-6.100. In the Center Creek watershed, infiltration of contaminated groundwater into the sewer system may be an additional source of metals loading to surface waters in this region of the state. As a result, where such groundwater infiltration occurs, domestic wastewater facilities may be potential contributors to dissolved metal impairments in this region of the state. In accordance with the Revised Statutes of Missouri Section 644.026.1(15) and 40 Code of Federal Regulations Part 122.41(e), operating permits for publically owned treatment works are required to operate and maintain collection systems in good working order, which includes the assessment and reduction of inflow and infiltration. A list of site-specific domestic wastewater facilities in the Center Creek watershed is presented in Table 12. Facilities determined to have a reasonable potential to cause or contribute to excursions of Missouri's dissolved zinc criteria have been assigned numeric effluent limits. None of the facilities listed in Table 12 discharge within the subwatersheds of Bens Branch or the tributary to Center Creek where dissolved lead or cadmium impairments occur. As previously stated, Center Creek is not impaired for dissolved lead or cadmium. For these reasons, domestic wastewater dischargers are not expected to cause or contribute to the impairments addressed by this TMDL.

Table 12. Site-specific domestic wastewater facilities in the Center Creek watershed.[17]

Facility Name	Permit Number	Design Flow ft^3/s	Actual Flow ft^3/s	Treatment Process	Metals Permit Limits (Daily/Monthly)	Permit Expires
Center Creek WWTF	MO0040185	7.440	4.09	Oxidation Ditch	Total Zinc 149/71µg/l	03/31/2023
Carl Junction WWTP	MO0025186	2.480	1.49	Oxidation Ditch	Total Zinc 233.1/104.2 µg/l	07/31/2022
Wentworth WWTF	MO0120634	0.026	0.017	Recirculating Sand Filter	None	09/30/2022
Ajinomoto Foods North America, Inc.	MO0002470	0.155	1.08	Mechanical Plant	Total Zinc 156/77 µg/l	12/31/2022
Hickory Lane Mobile Home Park	MO0115169	0.034	0.0121	Recirculating Sand Filter	None	12/31/2022
Coach Light RV Park	MO0116882	0.011	0.008	Recirculating Sand Filter	Total Zinc (Monitoring only)	12/31/2022
Bronc Busters WWTF	MO0125857	0.003	0.004	Recirculating Sand Filter	None	06/30/2023
Roger Hines Duplex Development	MO0117978	0.007	0.007	Three-cell Lagoon	Total Zinc (Monitoring only)	09/30/2022

[17] WWTF = wastewater treatment facility; WWTP = wastewater treatment plant

Malfunction Junction Mobile Home Park	MO0122793	0.009	0.005	No-discharge	None	12/31/2022
Sarcoxie WWTF	MO0028657	0.233	0.094	Three-cell Lagoon	Total Zinc (Monitoring only)	03/31/2023
Camp Mi Casa RV Park WWTF	MO0138011	0.300	0.300	No-discharge	None	03/31/2023

5.1.2 Industrial and Commercial Facilities

Industrial and commercial facilities discharge wastewater resulting from non-sewage generating activities and, in certain instances, can cause or contribute to metals impairments. At the time of this report, there are three site-specific permitted industrial facilities in the Center Creek watershed (Table 13). Under permit special conditions these facilities are required to establish Stormwater Pollution Prevention Plans. The plans must include a listing of contaminants of concern and best management practices (BMPs) to mitigate pollution from entering surface waters. Benchmark metals concentrations and routine monitoring are established for these facilities to evaluate the effectiveness of BMPs and determine if additional control measures are necessary.

Table 13. Site-specific industrial and commercial wastewater permitted facilities in the Center Creek watershed

Facility Name	Permit Number	Plant Category	Design Flow ft^3/s (m^3/s)	Actual Flow ft^3/s (m^3/s)	Treatment Process	Existing Metals Permit Conditions	Permit Expires
Dyno Nobel, Inc. Carthage	MO0002402	Major Non-muni	0.536 (0.02)	1.60 (0.045)	Settling Basin	Outfall Metals	07/31/2025
EBV Explosives Environmental	MO0113506	Industrial	0.002 (<0.0001)	0.002 (<0.0001)	Single-cell Lagoon	Stormwater Metals	12/31/2022
Expert Environmental Inc.	MO0002453	Industrial	Weather Dependent	Weather Dependent	Remediation Site	None	12/31/2022

Dyno Nobel (MO-0002402) is a commercial explosives manufacturer in Carthage, Missouri. The facility has made nitrate esters dynamite since the early 1990s. In addition to explosives, the facility produces mixed acids, dinitrated sulfuric acid, and ammonium nitrate. The facility currently monitors for a variety of metals. Discharges from the Dyno Nobel facility have potential to contribute dissolved metals loading, but are not expected to significantly contribute to the sediment toxicity impairments of Center Creek in comparison to potential loading from abandoned mine lands.

EBV Explosives Environmental (MO-0113506) is a hazardous waste storage and treatment facility located in Carthage, Missouri. The facility uses incineration and other unconventional technologies to treat and dispose of the following materials: ammunition, off-specification and outdated explosive and energetic devices, explosive/reactive materials, materials contaminated with explosive/reactive wastes, propellants and pharmaceutical materials containing nitroglycerin. The permittee generates both stormwater in contact with industrial activity and domestic wastewater. Domestic wastewater is treated by a no-discharge land application system and no industrial process

wastewater is discharged at this facility. Permit requirements for this facility require the development and implementation of a Stormwater Pollution Prevention Plan. Stormwater discharges from the facility are controlled and treated using BMPs. Discharges from this facility enter Grove Creek, WBID 3204, which available data shows to not be impaired due to metals.[18] For these reasons the EBV Explosives Environmental facility is not expected to be a significant contributor of pollutants to the impairments in Center Creek.

Expert Management Incorporated (MO-0002453) is a 246 acre property adjacent to EBV Explosives Environmental where former explosives production facilities existed. The site has undergone extensive remediation and maintains BMPs to reduce erosion and stormwater runoff. For these reasons it is expected any metals loading contributions from this facility to Center Creek are *de minimis*.

5.1.3 Abandoned Mine Lands

Stormwater runoff from waste piles as well as contaminated groundwater within abandoned mine lands in the Center Creek watershed are continuing sources of metals contamination to the impaired streams. Mine waste piles contain elevated levels of metals, which contaminate surrounding soils. Precipitation events can lead to perched water tables within mine waste piles, contaminating the water which is then released into the environment over time (Dames and Moore, 1993). Water bodies receiving water from these perched water tables or from receiving waters which flow through mine waste deposits are subject to elevated metal loading. Additionally, erosion of uncapped or unvegetated waste piles may result in transport of contaminated soils to nearby streams.

The Oronogo-Duenweg Mining Belt (ODMB), located in the western portion of the Center Creek watershed, is on EPA's National Priorities List for superfund remediation (USEPA, 2020). The National Priorities List is the list of sites of national priority among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States and its territories. EPA is given authority to place hazardous waste sites on the National Priorities List through provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA; U.S. Code Tile 42, Chapter 103). CERCLA, also known as Superfund, enables EPA to facilitate the remediation of hazardous waste sites and recover the associated costs by assessing the damages to public natural resources, establishing trustees, and providing oversight.

The Center Creek tributary and Bens Branch watersheds contain significant portions of the ODMB. An estimated 150 million tons of surface mine waste has contaminated approximately 11,000 acres across Jasper County. These mine wastes have contaminated surrounding soils and sediments within the Center Creek watershed. According to EPA's 2017 Five-Year Review Report for the ODMB, approximately 16 million cubic yards of contaminated material has been removed from 4,200 acres of land and transported to appropriate hazardous waste disposal sites. An estimated 10 million tons of waste materials still remain onsite (USEPA, 2017). Remedial activities in the ODMB include removal of contaminated yard soils, groundwater cleanup, and replacing residential connections to public drinking water supplies (USEPA, 2017). Feasibility studies are underway in other areas of the Spring

---

[18] Available data from a single sampling event in 2006 at the mouth of Grove Creek and at 0.5 miles above the mouth show dissolved cadmium and lead values below the detection limit (<5.0 μg/L cadmium and <10.0 μg/L lead).

River Basin to address erosional and runoff contamination from hazardous source materials to surface waters. These feasibility studies are expected to be completed in 2022, which is also the year the next Five-Year Review will be completed for the ODMB. Ultimately, remedial actions completed within the watershed are expected to improve water quality. Future remedial actions should be reviewed to determine the impacts on water quality and contaminant source loading.

Other mining related activities also contribute to the metals contamination in the region. For example, mine tailings were often reprocessed resulting in fine-grained waste materials that are more prone to erosional and transport processes. These fine particles can have high concentrations of cadmium, lead, and zinc (Schaider, et al., 2007). Processed tailings have also been used as aggregate for road construction and fill activities throughout the region, including backfill for sewage collection lines.

It is important to note, active and abandoned mine areas can be classified as point sources due to the nature of mining and milling activities, regardless if they are currently under an active permit (USEPA, 1993). Although remediation activities are ongoing, abandoned mines and related activities are the most significant sources of metals loading and contamination in the Center Creek watershed.

5.1.4 Concentrated Animal Feed Operations

Concentrated Animal Feeding Operations (CAFOs) are animal feeding operations that confine, feed, or maintain more than 1,000 animal units for 45 days or more during any 12-month period. Facilities with fewer animal units may be permitted as CAFOs if discharges occur or other water quality issues are discovered per 10 CSR 20-6.300. In Missouri, these types of facilities are permitted with either a site-specific permit or one of two available CAFO general permits (MO-G01 or MO-GS). Under the MO-G01 permit, CAFO facilities are not permitted to discharge manure or process wastewater, but exceptions are granted for situations where either a catastrophic storm event or a chronic wet weather event, as they are defined in the permit, overwhelms the facility's designed storage volume.[19] Under the MO-GS1 permit, CAFO facilities are not allowed to discharge for any reason, without exception. Under this permit, both direct discharge and runoff occurring during land application is a violation. Animal wastes generated from CAFOs that are transported by stormwater runoff or by wastewater discharges are not expected to be a significant source of metals loading to the impaired streams. Five CAFO facilities are present in the Center Creek watershed (Table 14).

Table 14. CAFOs in the Center Creek watershed

Facility Name	Permit Number	Permit Type	Expires[20] (Mo/Day/Year)	Class[21]	Animal Type
G.L. Farms	MO-GS10412	General	1/28/2023	IC	Broilers

[19] Storage structures should be properly designed, constructed, operated, and maintained to contain all manure, litter, process wastewater plus the runoff and direct precipitation from the 25-year, 24-hour design storm event for the location of the CAFO.
[20] When a permit expires, a facility remains bound by the conditions of that expired permit until either the permit is terminated or a new permit is issued.
[21] An operation's "class size" is a category that is based upon the total number of animal units confined at an operation. Class IC facilities contain 1,000 to 2,999 animal units. 1,000 animal units is equal to 2,500 swine; 100,000 broilers; 700 dairy cows; or 1,000 beef steers.

Lil Peckers LLC	MO-GS10439	General	1/28/2023	IC	Broilers
A and H Farms, LLC	MO-GS10271	General	1/28/2023	IC	Broilers
Dragon Star Farm	MO-GS10267	General	1/28/2023	IC	Broilers
KH Farm, LLC	MO-GS10524	General	1/27/2018	IC	Broilers

5.1.5 Municipal Separate Storm Sewer System

A MS4 is a stormwater conveyance system owned by a public entity which is not a combined sewer or part of a sewage treatment plant. Federal regulations issued in 1990 require discharges from such systems to be regulated by permits if the population of a municipality or, in some cases, a county, is 100,000 or more. In 1999, new federal regulations require permits for discharges from small MS4s located within a U.S. Census Bureau defined urban area or have otherwise been designated as needing a permit by the permitting authority. There are eight permitted MS4s in the Center Creek watershed (Table 15). Permitted MS4s in the Center Creek watershed include six municipalities, unincorporated areas of Jasper County, and Missouri Department of Transportation (MoDOT) rights-of-way located within the U.S. Census Bureau urban area. Areas with regulated MS4s account for approximately 30.0 square miles (10 percent) of the total Center Creek watershed area, 1.1 square miles (37 percent) of tributary to Center Creek watershed area, and 4.6 square miles (73 percent) of Bens Branch watershed area.

Table 15. Permitted MS4s in the Center Creek watershed

Permitted Holder	Permit Number	Permit Type	Expiration Date
Carl Junction Small MS4	MO-R040028	General	September 30, 2021
Carterville Small MS4	MO-R040085	General	September 30, 2021
Carthage Small MS4	MO-R040017	General	September 30, 2021
Jasper County Small MS4	MO-R040048	General	September 30, 2021
Joplin Small MS4	MO-R040041	General	September 30, 2021
Oronogo Small MS4	MO-R040109	General	September 30, 2021
Web City Small MS4	MO-R040046	General	September 30, 2021
MoDOT TS4[22]	MO-0137910	Site-Specific	October 31, 2021

Typically, stormwater discharges from MS4s have not been associated with metals impairments in Missouri. However, in the areas surrounding the Tri-State Mining District waste rock from milling processes were often moved off site and used as fill material for road constructions, back fill for sewage lines, and other construction efforts (MoDNR and DOI, 2002). These materials are higher in metal concentrations than background soil and water conditions, and may be a source of metals loading to surrounding water bodies. The removal and capping of residential yards contaminated with fill materials began in 1996, with EPA completing removal of contaminated soils from 2,291 residential yards by September 2001. Although an additional 30 residents refused initial EPA remediation efforts, the Department completed remediation actions on these remaining residential

[22] TS4 = transportation separate storm sewer system

properties by August 2010. Per the request of EPA, the Jasper County Commission promulgated a building ordinance in 2006 requiring testing of soils for new residential construction planned on contaminated lands (USEPA, 2017). With fill removal and capping actions completed in 2012, discharges from the MS4 are not expected to contribute significant amounts of metals loading to the impaired streams.

5.1.6 Other General Wastewater and Stormwater Discharges

General permits are issued based on the type of activity occurring and are intended to be flexible enough to allow for ease and speed of issuance, while providing the required protection of water quality. General permits are issued for activities similar enough to be covered by a single set of requirements and are designated with permit numbers beginning with “MO-G” or “MO-R,” respectively. Permits associated with construction or land disturbance activities (MO-RA) are temporary. The number of permits of this type may vary in any given year. Table 16 presents a list of general and stormwater permits in the Center Creek watershed, as of April 7, 2020.

Table 16. General (MO-G) and stormwater (MO-R) permitted facilities in the Center Cr. watershed.

Permit No.	Facility Name	Permit Type	Discharge Type	Expiration Date
MOG350273	MFA Oil Bulk Plant - Sarcoxie	Petroleum Storage <250,000 gal	Stormwater	9/17/2022
MOG490801	A-1 Quality Stone Joplin Quarry	Limestone Quarries	Stormwater	4/30/2022
MOG491496	G and H Redi-Mix Carthage	Limestone Quarries	Stormwater	4/30/2022
MOG491506	Erie 2020 Joplin Airport	Limestone Quarries	Stormwater	4/30/2022
MOG920015	Double O Organics	Feedstock Composting	Stormwater	1/24/2023
MOR130142	Schreiber Foods Inc - Fairview	Food and Kindred	Stormwater	9/6/2023
MOR203336	Leggett and Platt Machine Products	Metal Fabrications/Light Ind.	Stormwater	8/31/2024
MOR203510	TAMKO Building Products LLC - Webb City	Metal Fabrications/Light Ind.	Stormwater	8/31/2024
MOR22A028	Heritage Oak, LLC	Lumber and Wood Primary	Stormwater	9/16/2024
MOR23A130	Reagent Chemical and Research, Inc.	Chemical	Stormwater	10/31/2020
MOR60A183	Missouri Metal Recycling	Motor Vehicle Salvage	Stormwater	12/11/2023
MOR60A249	Keeter's Auto	Motor Vehicle Salvage	Stormwater	12/11/2023
MOR60A276	Missouri Mustang LLC	Motor Vehicle Salvage	Stormwater	12/11/2023
MOR60A308	US Assets 43 AND 96 HWY Workshop	Motor Vehicle Salvage	Stormwater	12/11/2023
MOR60A326	Frossard Residence	Motor Vehicle Salvage	Stormwater	12/11/2023
MOR60A367	M and M Wrecker Service of SWMO LLC	Motor Vehicle Salvage	Stormwater	12/11/2023
MOR60A436	Cottrills Towing	Motor Vehicle Salvage	Stormwater	12/11/2023
MOR60A439	R and T Salvage Inc	Motor Vehicle Salvage	Stormwater	12/11/2023
MOR80C056	Tri State Motor Transit Co	Motor Freight Transportation	Stormwater	11/30/2022
MOR80F046	Joplin Regional Airport	Airports	Stormwater	11/27/2022
MORA10028	Kleiboeker's Clover Creek Farms	Construction or Land Disturbance	Stormwater	2/7/2022
MORA10121	Heritage Acres Plat #14	Construction or Land Disturbance	Stormwater	2/7/2022
MORA10150	John and Robyn Kleiboeker	Construction or Land Disturbance	Stormwater	2/7/2022
MORA10304	Weatherstone Stormwater Improvements	Construction or Land Disturbance	Stormwater	2/7/2022

Permit No.	Facility Name	Permit Type	Discharge Type	Expiration Date
MORA10914	Line FS Pressure Test	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11004	Briar Meadow Estates Plat 5	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11076	County Road 110 Bridge	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11336	ECWB Properties, LLC	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11339	Mando Lane Subdivision	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11592	Stadium View	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11595	Fountain Estates	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11596	Fox Briar Subdivisions	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11828	Metro Builders Supply	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11935	Center Creek 201 WWTP	Construction or Land Disturbance	Stormwater	2/7/2022
MORA11961	Northtown Village, Inc.	Construction or Land Disturbance	Stormwater	2/7/2022
MORA12075	Atwoods Ranch and Home	Construction or Land Disturbance	Stormwater	2/7/2022
MORA12158	17th Place Apartments	Construction or Land Disturbance	Stormwater	2/7/2022
MORA12383	Chesterfield Estates	Construction or Land Disturbance	Stormwater	2/7/2022
MORA12485	Superior Steel Sales - Sales Office	Construction or Land Disturbance	Stormwater	2/7/2022
MORA12648	Webb City Warehouse	Construction or Land Disturbance	Stormwater	2/7/2022
MORA12786	Fox Briar 6	Construction or Land Disturbance	Stormwater	2/7/2022
MORA13114	JT Farm	Construction or Land Disturbance	Stormwater	2/7/2022
MORA13259	Apple Rd. and CR 170	Construction or Land Disturbance	Stormwater	2/7/2022
MORA13367	Briarbrook Plaza	Construction or Land Disturbance	Stormwater	2/7/2022
MORA13625	Dogwood Trails Plat 3	Construction or Land Disturbance	Stormwater	2/7/2022
MORA13676	Hermanns Site	Construction or Land Disturbance	Stormwater	2/7/2022
MORA13699	Community Bank and Trust	Construction or Land Disturbance	Stormwater	2/7/2022
MORA14677	Jasper County PWSD #3	Construction or Land Disturbance	Stormwater	2/7/2022
MORA14948	Boyers Farm	Construction or Land Disturbance	Stormwater	2/7/2022
MORA15308	Carthage DC Foods	Construction or Land Disturbance	Stormwater	2/7/2022
MORA15474	Memory Care Facility - Foxberry Terrace	Construction or Land Disturbance	Stormwater	2/7/2022
MORA16062	Belle Starr Subdivisions	Construction or Land Disturbance	Stormwater	2/7/2022

General permitted activities described in Table 16, as well as any future general or stormwater permitted activities, must be conducted in compliance with all permit conditions, including monitoring and discharge limitations. It is expected compliance with these permits will be protective of the applicable designated uses within the watershed. For these reasons, general permits are not expected to cause or contribute to the metals impairment of Center Creek, Bens Branch, and Center Creek tributary. If, at any time, the Department determines the water quality of streams in the watershed is not being adequately protected, the Department may require the owner or operator of a permitted site to obtain a site-specific operating permit per 10 CSR 20-6.010(13)(C).

5.1.7 Illicit Straight Pipe Discharges

Illicit straight pipe discharges of domestic wastewater are potential point sources of pollutants to surface waters. These types of sewage discharges bypass treatment systems, such as a septic tank or a sanitary sewer, and discharge directly to a stream or an adjacent land area (Brown and Pitt 2004). Illicit straight pipe discharges are illegal and not authorized under the federal Clean Water Act. At present, there are no data available about the presence or number of illicit straight pipe discharges in the Center Creek watershed. For this reason, it is unknown to what significance straight pipe discharges contribute metal loads to surface waters in the watershed. Because straight pipe discharges are associated with domestic and household wastewater, metal contributions from illicit straight pipe discharges are expected to be minor. For purposes of this TMDL, it is assumed that illicit straight pipe discharges do not contribute metal loads above *de minimis* concentrations. Due to the illegal nature of these discharges, any identified illicit straight pipe discharges must be eliminated. Elimination of illicit discharges is a requirement of MS4 permits.

5.2 Nonpoint Sources

Nonpoint sources are diffuse sources with no discernible, confined, or discrete conveyance, and include all categories of discharge that do not meet the definition of a point source. Nonpoint sources are not regulated under the federal Clean Water Act and are exempt from Department permit regulations per state rules at 10 CSR 20-6.010(1)(B)1. Nonpoint source pollutants are typically transported by stormwater runoff, which is minor or negligible during dry weather conditions. In general, activities typically associated with nonpoint source pollutant loading, such as crop cultivation and livestock grazing, are not expected to contribute significant amounts of cadmium, lead, or zinc to Center Creek, Bens Branch, or Center Creek tributary.

As stated in Section 5.1, EPA considers historical mining areas as point sources. Due to the wide extent of mining in the Tri-State Mining District and the Oronogo-Duenweg Mining Belt, metals loading is likely ubiquitous throughout the Center Creek watershed. Sources of metals loading in the watershed include numerous mine-waste piles, groundwater discharges from underground mines, and widespread exposure of mineral-laden limestone, which are all potential sources for movement of mine wastes offsite. However, vegetated areas such as forest or grassland, which make up the majority of land cover outside of mining areas in the watershed, should limit erosion and reduce the potential of contaminated sediments from entering waterways. Risks of soil erosion from cropland areas are greatest during field preparation and tillage, but these periods of disturbance are expected to be infrequent and seasonal. Additionally, when compared to other land cover, cultivated crop lands susceptible to tillage and erosion in these watersheds is quite small. (see Table 5.) For these reasons, any nonpoint source metals loading via runoff or erosion is expected to be *de minimis* and does not contribute to the cadmium, lead, or zinc impairments in Center Creek, Bens Branch, or Center Creek tributary.

Although metals loading from nonpoint sources is not likely to result in violations of Missouri's Water Quality Standards, legacy metal loads already present in stream systems can be sources of metals loading during higher flows. As conservative pollutants, metals contained in the benthic sediments do not degrade, can become re-suspended into the water column, and carried downstream via natural fluvial processes. Such re-suspension may occur during and immediately following high-flow storm events and allow previously environmentally unavailable metals to enter the water column (Andrews et al., 2009).

6. Calculating Loading Capacity

A TMDL is equal to the loading capacity of a water body for a specific pollutant, which is the maximum pollutant load that a water body can assimilate and still attain and maintain water quality standards. The loading capacity is derived from the numeric water quality criterion for each pollutant or an appropriate surrogate when no numeric criterion is applicable. Once the maximum allowable pollutant load is determined, a portion is assigned to point sources as a wasteload allocation and to nonpoint sources as a load allocation. A margin of safety is required to account for uncertainties in scientific and technical understanding of water quality in natural systems (CWA Section 303(d)(l)(C) and 40 CFR 130.7(c)(l)). The loading capacity is equal to the sum of the wasteload allocation, load allocation, and the margin of safety as follows:

$$TMDL = LC = \sum WLA + \sum LA + MOS$$

where LC is the loading capacity, ∑WLA is the sum of the wasteload allocations, ∑LA is the sum of the load allocations, and MOS is the margin of safety.

7. Total Maximum Daily Loads

According to 40 CFR 130.2(i), TMDLs can be expressed in terms of mass per unit time, toxicity, or other appropriate measures. The TMDLs for Center Creek, Bens Branch, and Center Creek tributary are expressed as pounds per day using load duration curves developed using the cadmium, lead, and zinc criteria, all possible stream flows, and a unit conversion factor.[23] Establishing TMDLs using load duration curves is consistent with the Anacostia Ruling (*Friends of the Earth, Inc., et al v. EPA*, No 05-5010, April 25, 2006) and EPA guidance in response to that ruling (USEPA 2006; USEPA 2007a).

As noted in Section 3.2 of this document, Missouri's Water Quality Standards include specific numeric metals and general criteria for waters designated for the protection warm water of aquatic life. Metals concentrations consistent with Missouri's dissolved metals criteria found in Table A2 and are protective of warm water aquatic life in the water column. No specific numeric metals criteria are available for sediment toxicity in Missouri. In order to understand the extent to which sediment toxicity could be contributing adverse effects to the aquatic environment in the Center Creek watershed, equilibrium partitioning methodology was applied (USEPA 1999).[24] Because the metals of concern follow a defined partitioning behavior between pore water and sediment, measured metals concentrations in sediment were used to estimate potential exposures in the water column based on equilibrium partitioning principles. These principles generally state that when a metal resides in sediment, it exists in equilibrium with pore water, and when physical-chemical properties are known, the partitioning behavior of the metal between the solid (sediment) and aqueous (pore water) phase

[23] $\boldsymbol{Load}\left(\frac{\text{count}}{\text{time}}\right) = \boldsymbol{Concentration}\left(\frac{\text{count}}{\text{volume}}\right) * \boldsymbol{Flow}\left(\frac{\text{volume}}{\text{time}}\right) * \boldsymbol{conversion\ factor}\ (5.395)$

[24] The 1999 EPA document that is cited, from which equilibrium partitioning coefficients are derived, primarily addresses metals contamination from groundwater. Due to the likelihood of groundwater contributions to the impairments in the Center Creek watershed, as described in Section 2.1, Section 4, and Section 5.1.3 of this document, this approach is appropriate for estimating existing pore water concentrations and provides conservative reduction targets. This information is used to estimate existing loads only and was not used in the calculation of pollutant loading capacities.

can be predicted (Hansen et al., 2005). Knowing stream sediments in the Center Creek watershed are comprised of metals contaminated material, elevated dissolved cadmium, lead, and zinc have a significant impact on aquatic life in the pore water environment. Following the equilibrium partitioning procedure, measured cadmium, lead, and zinc in sediment data were used to back-calculate pore water concentrations. Using pore water as a surrogate for metals concentrations in sediment, the dissolved metals criteria can be used as the numeric targets for TMDL development to address both water and sediment impairments in the Center Creek watershed. The use of pore water concentration targets addresses the critical low flow conditions when dilution is not available and protects benthic invertebrate aquatic life living in direct contact with the pore water. Pore water concentrations for heavy metals ($Metal_{pw}$), such as cadmium, lead, and zinc, are estimated by applying the following equation:

Equation 1: $\mathbf{Metal_{pw},\ \mu g/L = Metal_{sed,\ mg/kg}/(K_d,mL/g)*(1{,}000\ \mu g/mg)}$

where $Metal_{pw}$ is the pore water concentration, $Metal_{sed}$ is the metal in sediment concentration and K_d is the distribution coefficient. Based on “Partition Coefficients for Lead” from EPA (USEPA 1999), a polynomial relationship existed between the K_d value and soil pH measurements as follows:

Equation 2: $\mathbf{(K_{d(Pb),\ mL/g}) = 1639 - 902.4(pH) + 150.4(pH)^2}$

In addition, the relationship between the K_d value and equilibrium concentrations of lead at a fixed pH can be expressed as:

Equation 3: $\mathbf{(K_{d(Pb),\ mL/g}) = 9{,}550\ C^{-0.335}}$

where C is the equilibrium concentration of lead in µg/L.

For cadmium, an estimation of pore water concentration can be derived using a similar approach. Based on “Partition Coefficients for Cadmium” from the same publication (USEPA 1999), The relationship between the K_d for cadmium and pH is best described in a linear fashion as provided in “Partition Coefficients for Cadmium” (USEPA 1999):

Equation 4: $\mathbf{\log_{10}[K_{d(Cd)}] = -0.54 + 0.45(pH)}$

Values for sediment pore water pH are not known. However, the Cedargap soil, from which the stream sediment substantially originates, tends to range from slightly acidic to acidic. Values for pH range from 5.6 to 6.7 (NRCS, 2020). A pH value of 5.6 was applied to reflect acidic environmental conditions.

EPA provides look-up tables for the estimated range (i.e., median, mean, maximum, minimum) of K_d values for zinc (USEPA, 2005). The mean $K_{d(Zn)}$ value was applied to develop the sediment pore water concentration relationship. $K_{d(Zn)}$ values were derived from twenty-one literature referenced values. The resulting values have a relative confidence value of one (1 = highest; 4 = lowest).

Table 17 presents the applied calculated metals criteria used for TMDL development, the associated hardness for calculating each criterion, and the corresponding water body for which the TMDL targets apply. Chronic criteria concentrations are used as TMDL targets to calculate daily loads and will also provide aquatic life protection from acute toxicity events. Additionally, these dissolved metal targets are below consensus-based Threshold Effect Concentration values that identify contaminant concentrations below which harmful effects on benthic aquatic life are not expected (Macdonald et al., 2000). For these reasons the selected TMDL targets are protective of warm water habitat (aquatic life) and through use of the equilibrium partitioning method will result in attainment of water quality standards associated with both specific and general criteria. The resulting load duration curves, based on these targets, provide a visual representation of the pollutant loading capacity of the water bodies at all stream flows. Using this approach, the available loading capacity of the stream varies with flow, but the pollutant concentration remains constant. Additional discussion about the methods used to develop the load duration curves for Center Creek, Bens Branch, and Center Creek tributary is provided in Appendix C.

Table 17. Chronic dissolved metals criteria applied as TMDL targets

Water Body	Water Body ID	Pollutant	Criteria (µg/L)	Applied Median Hardness (mg/L)
Center Creek	3203	Cadmium Lead	1.08 4.52	172
Center Creek Tributary	5003	Cadmium Lead Zinc	1.08 4.52 185.91	172
Bens Branch	3980	Cadmium Lead Zinc	1.08 4.52 185.91	172

To ensure adequate protection of downstream water quality, consistent with the general criterion at 10 CSR 20-7.031(4)(E), the most stringent downstream criteria associated with Center Creek was applied to all upstream impaired segments. This ensures loading from Bens Branch and Center Creek tributary is protective of water quality in Center Creek. This also ensures downstream protection at the Center Creek confluence with the Spring River. Additional flows and dilution from the larger Spring River is expected to result in additional reductions to pollutant concentrations originating from Center Creek. Missouri's criteria for cadmium, lead, and zinc are equivalent to EPA's national recommended water quality criteria for the protection of aquatic life. For this reason, these targets will be protective of downstream water quality. The pollutant load reductions resulting from implementation of this TMDL will provide additional water quality improvements in Kansas.

Figures 8 through 15 are the TMDL load duration curves for the impaired streams in the Center Creek watershed. The load duration curves represent the streams' loading capacities over the range of flows estimated to occur in the water body. In the following figures, the y-axis describes metal loading as pounds per day and the x-axis represents the frequency for which a particular flow is met or exceeded. Lower flows are equaled or exceeded more frequently than higher flows. The individually plotted monitoring data were calculated by converting each sample's metals concentrations to a daily load using the area corrected daily flow for the sampling date. These observed loads are presented only to illustrate flow conditions under which excessive metals

loading may be occurring, and may be used to estimate the amount of pollutant reduction needed to attain water quality standards. These observed loads were not used in the calculations for loading capacity or allocations. The flow condition ranges and descriptions presented in the figure illustrate general base-flow and surface-runoff conditions consistent with EPA guidance about using load duration curves for TMDL development (USEPA 2007b). Tables 18 - 25 provide summaries of the TMDL loading capacities and allocations for selected flow exceedances from the load duration curves. Specific allocations for individual sources are discussed in Sections 8 and 9.

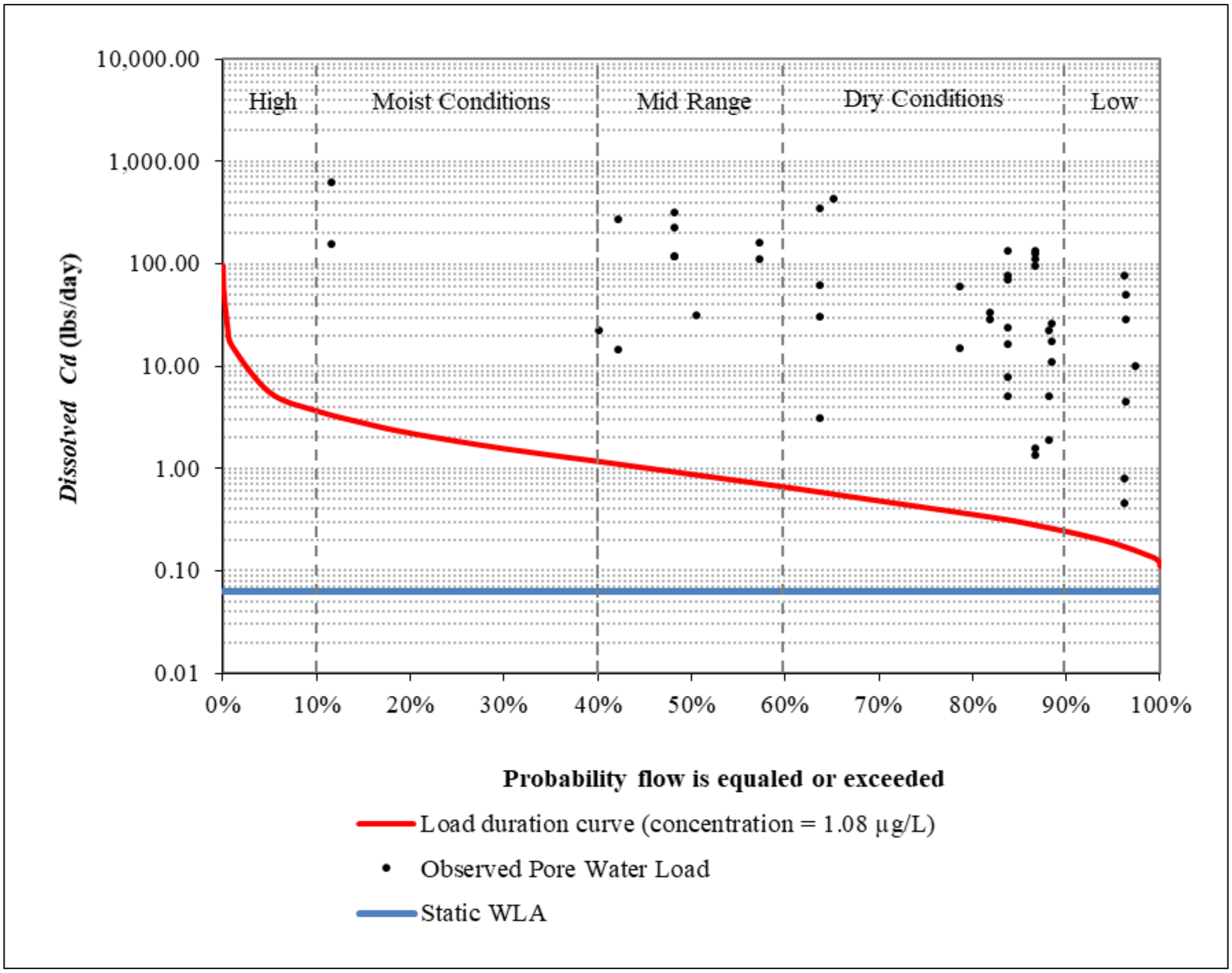

Figure 8. Dissolved cadmium TMDL for Center Creek, WBID 3203.

Table 18. Dissolved cadmium TMDL and allocation values for Center Creek at selected flows.

Percent of time flow equaled or exceeded	Flow ft^3/s	TMDL (pounds/day)	∑WLA* (pounds/day)	∑LA (pounds/day)	MOS (pounds/day)
95	32.3	0.19	0.09	0.08	0.02
75	70.4	0.41	0.11	0.26	0.04
50	151.1	0.88	0.17	0.62	0.09
25	317.4	1.85	0.29	1.37	0.18
5	945.2	5.51	0.74	4.22	0.55

*Total WLA is the sum of both static and flow varying allocations.

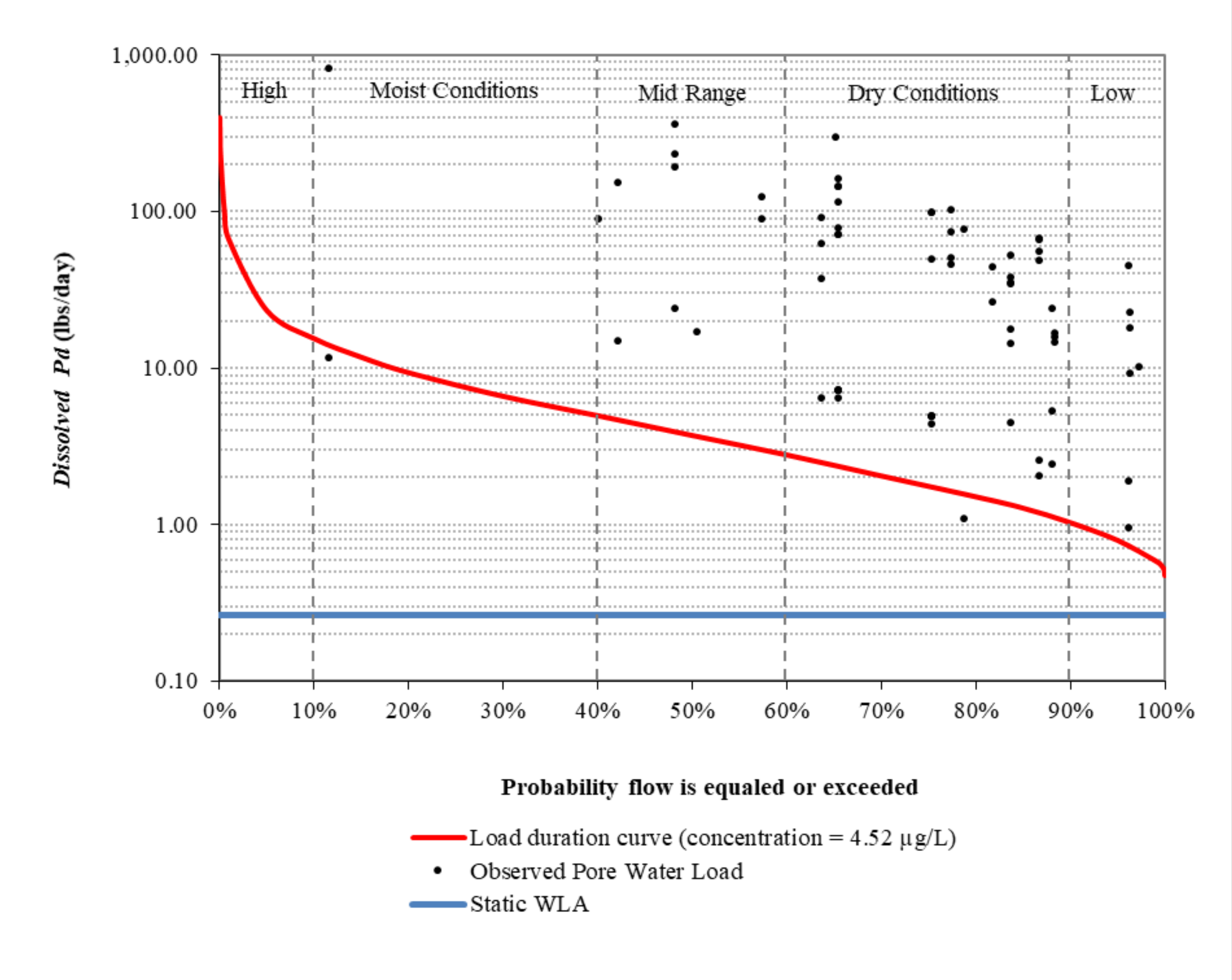

Figure 9. Dissolved lead TMDL for Center Creek, water body ID 3203.

Table 19. Dissolved lead TMDL and allocation values for Center Creek at selected flows.

Percent of time flow equaled or exceeded	Flow ft³/s	TMDL (pounds/day)	∑WLA* (pounds/day)	∑LA (pounds/day)	MOS (pounds/day)
95	32.3	0.79	0.36	0.35	0.08
75	70.4	1.72	0.48	1.07	0.17
50	151.1	3.68	0.71	2.60	0.37
25	317.4	7.74	1.21	5.75	0.77
5	945.2	23.04	3.08	17.66	2.30

*Total WLA is the sum of both static and flow varying allocations.

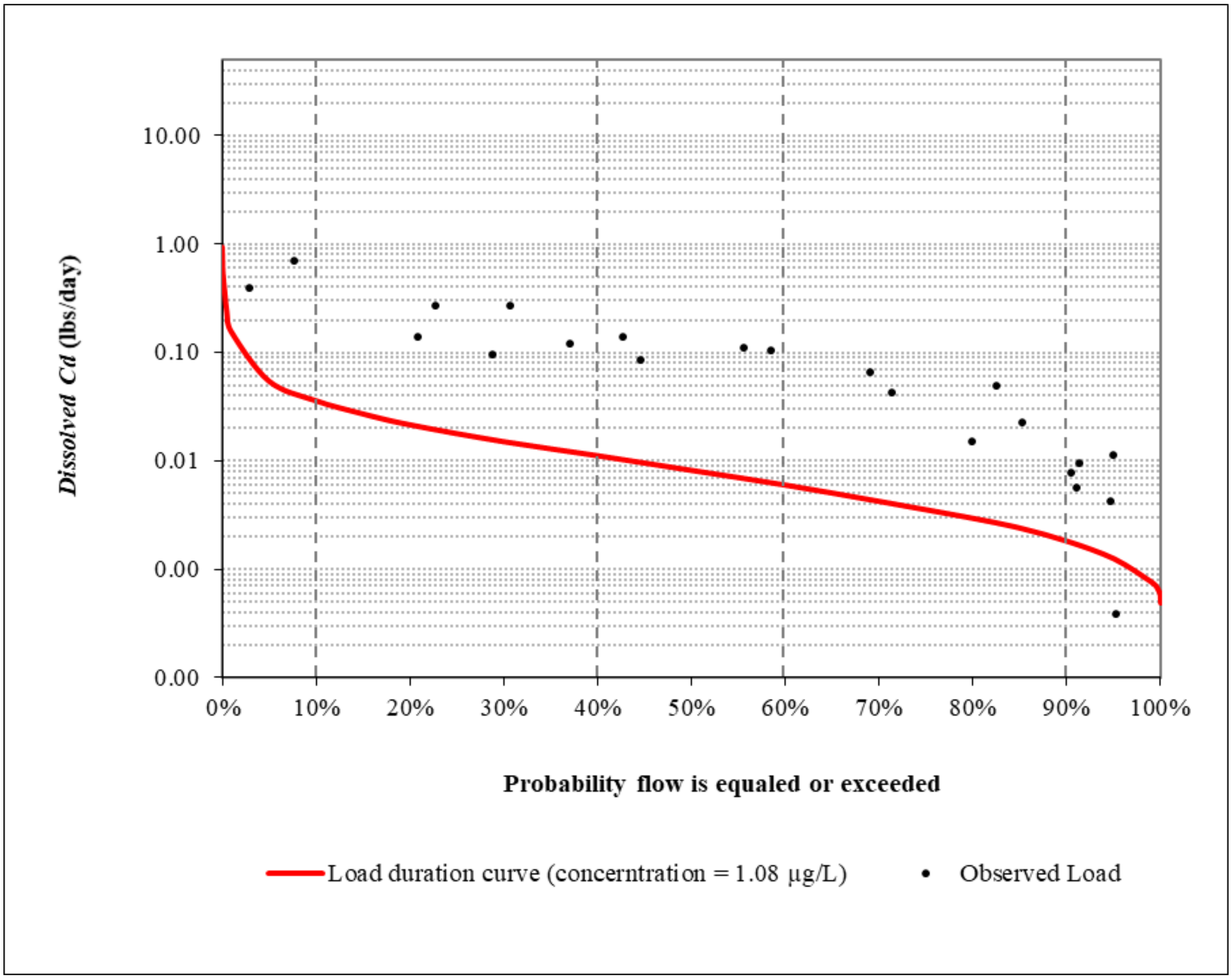

Figure 10. Dissolved cadmium TMDL for Center Creek tributary, water body ID 5003.

Table 20. Dissolved cadmium TMDL and allocation values for Center Creek tributary (WBID 5003) at selected flows.

Percent of time flow equaled or exceeded	Flow ft^3/s	TMDL (pounds/day)	∑WLA (pounds/day)	∑LA (pounds/day)	MOS (pounds/day)
95	0.2	0.0012	0.0005	0.0007	0.0001
75	0.6	0.0035	0.0013	0.0018	0.0003
50	1.4	0.0082	0.0030	0.0043	0.0008
25	3.1	0.0179	0.0066	0.0094	0.0018
5	9.3	0.0544	0.0202	0.0287	0.0054

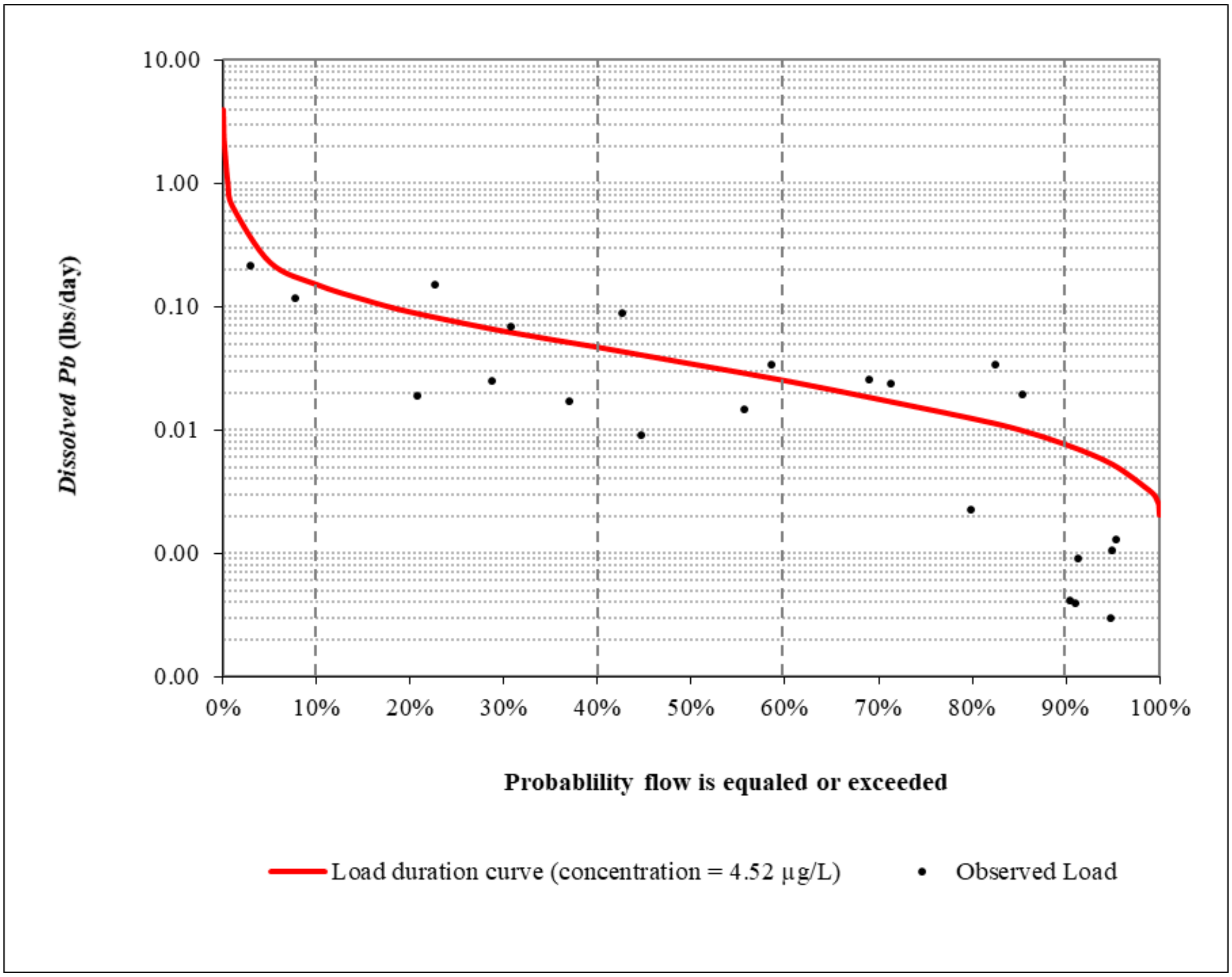

Figure 11. Dissolved lead TMDL for Center Creek tributary, water body ID 5003.

Table 21. Dissolved lead TMDL and allocation values for Center Creek tributary (WBID 5003) at selected flows.

Percent of time flow equaled or exceeded	Flow ft^3/s	TMDL (pounds/day)	∑WLA (pounds/day)	∑LA (pounds/day)	MOS (pounds/day)
95	0.2	0.0052	0.0019	0.0028	0.0005
75	0.6	0.0145	0.0054	0.0077	0.0015
50	1.4	0.0342	0.0127	0.0180	0.0034
25	3.1	0.0747	0.0278	0.0395	0.0075
5	9.3	0.2278	0.0847	0.1203	0.0228

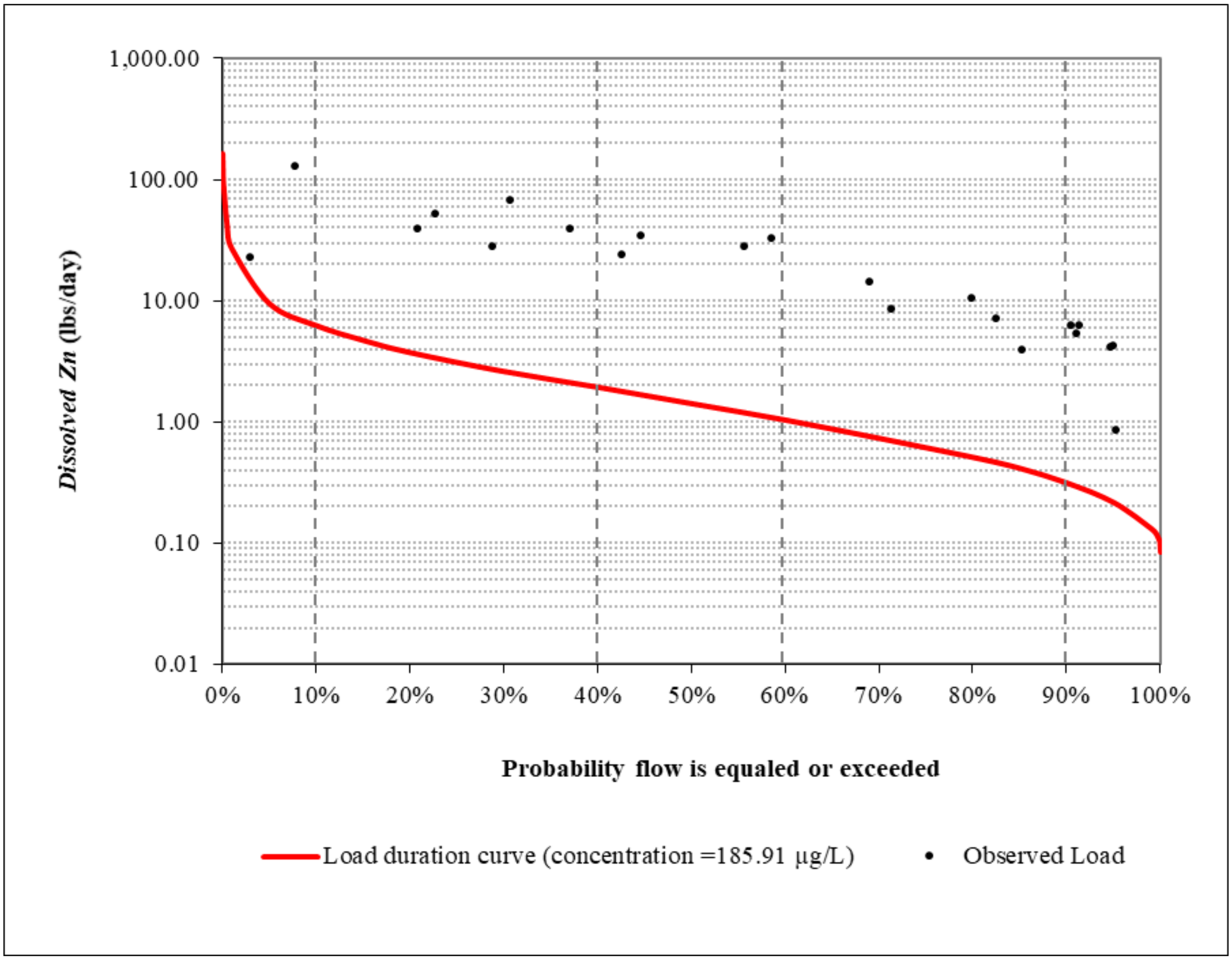

Figure 12. Dissolved zinc TMDL for Center Creek tributary, water body ID 5003.

Table 22. Dissolved zinc TMDL and allocation values for Center Creek tributary (WBID 5003) at selected flows.

Percent of time flow equaled or exceeded	Flow ft^3/s	TMDL (pounds/day)	∑WLA (pounds/day)	∑LA (pounds/day)	MOS (pounds/day)
95	0.2	0.21	0.08	0.11	0.02
75	0.6	0.60	0.22	0.32	0.06
50	1.4	1.41	0.52	0.74	0.14
25	3.1	3.07	1.14	1.62	0.31
5	9.3	9.37	3.48	4.95	0.94

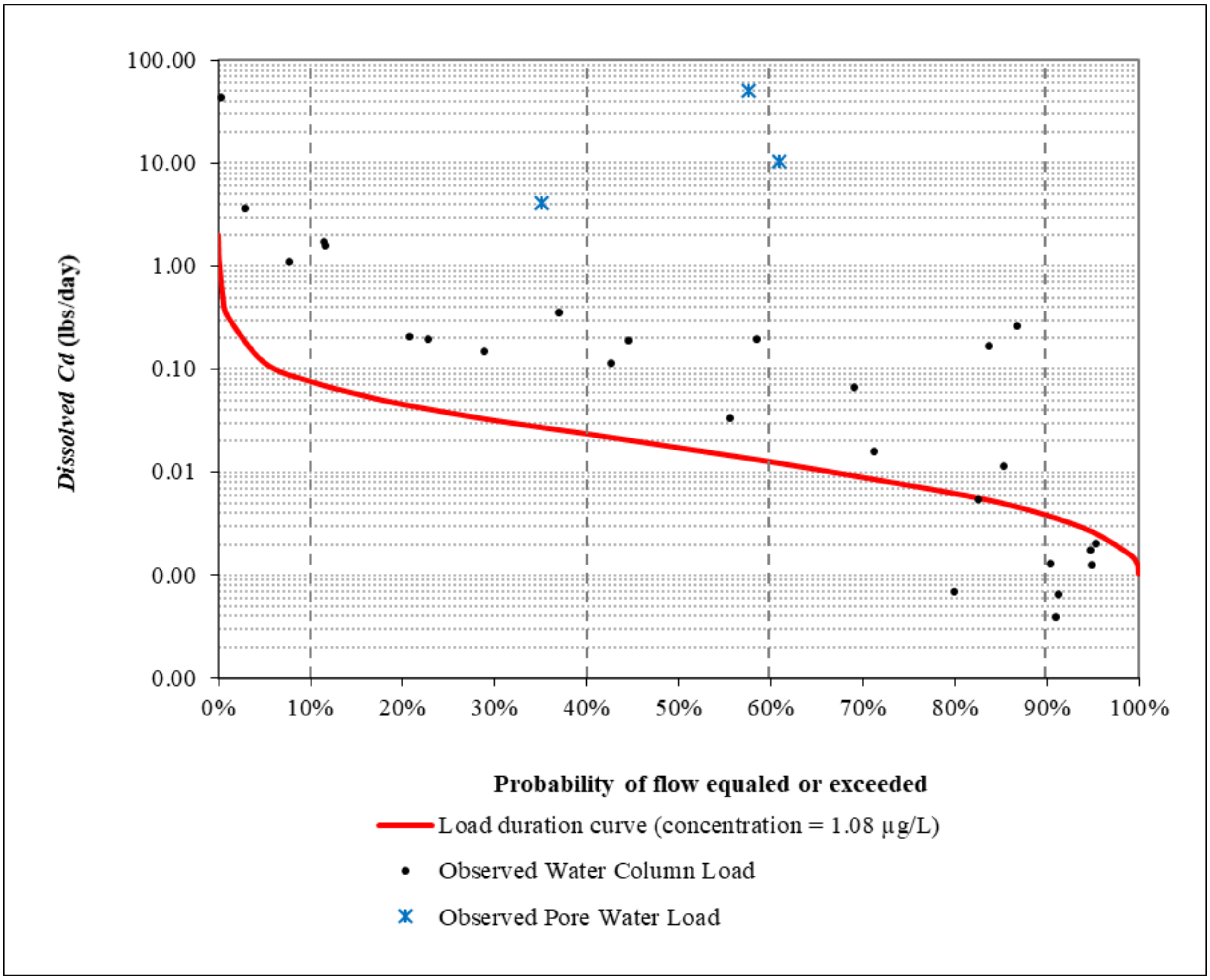

Figure 13. Dissolved cadmium TMDL for Bens Branch, water body ID 3980.

Table 23. Dissolved cadmium TMDL and allocation values for Bens Branch (WBID 3980) at selected flows.

Percent of time flow equaled or exceeded	Flow ft^3/s	TMDL (pounds/day)	∑WLA (pounds/day)	∑LA (pounds/day)	MOS (pounds/day)
95	0.45	0.0026	0.0019	0.0005	0.0003
75	1.26	0.0073	0.0053	0.0013	0.0007
50	2.96	0.0173	0.0125	0.0030	0.0017
25	6.48	0.0377	0.0274	0.0065	0.0038
5	19.75	0.1150	0.0836	0.0199	0.0115

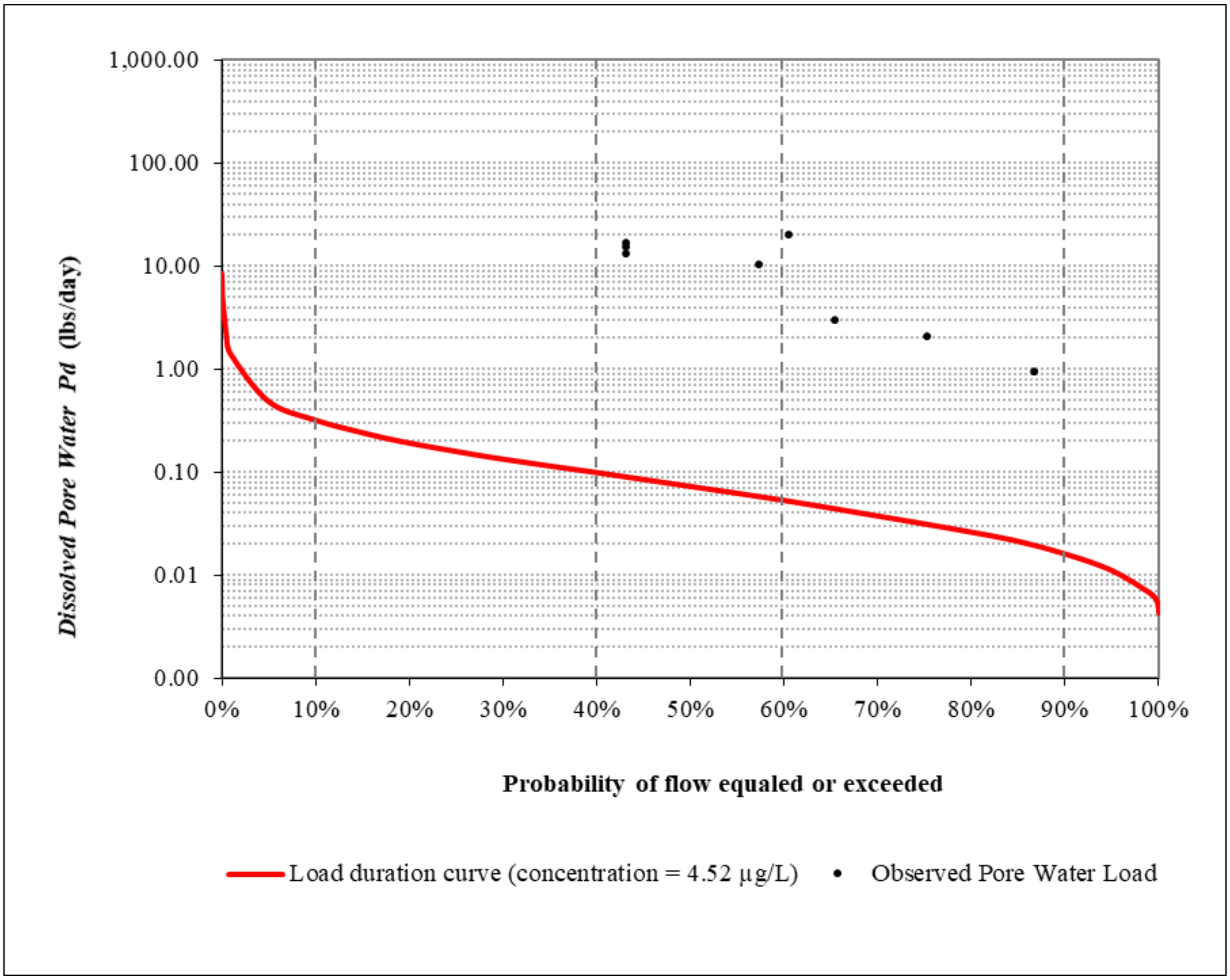

Figure 14. Dissolved lead TMDL for Bens Branch, water body ID 3980.

Table 24. Dissolved lead TMDL and allocation values for Bens Branch (WBID 3980) at selected flows.

Percent of time flow equaled or exceeded	Flow ft^3/s	TMDL (pounds/day)	∑WLA (pounds/day)	∑LA (pounds/day)	MOS (pounds/day)
95	0.5	0.01	0.008	0.002	0.001
75	1.3	0.03	0.022	0.005	0.003
50	3.0	0.07	0.053	0.012	0.007
25	6.5	0.16	0.115	0.027	0.016
5	19.7	0.48	0.350	0.083	0.048

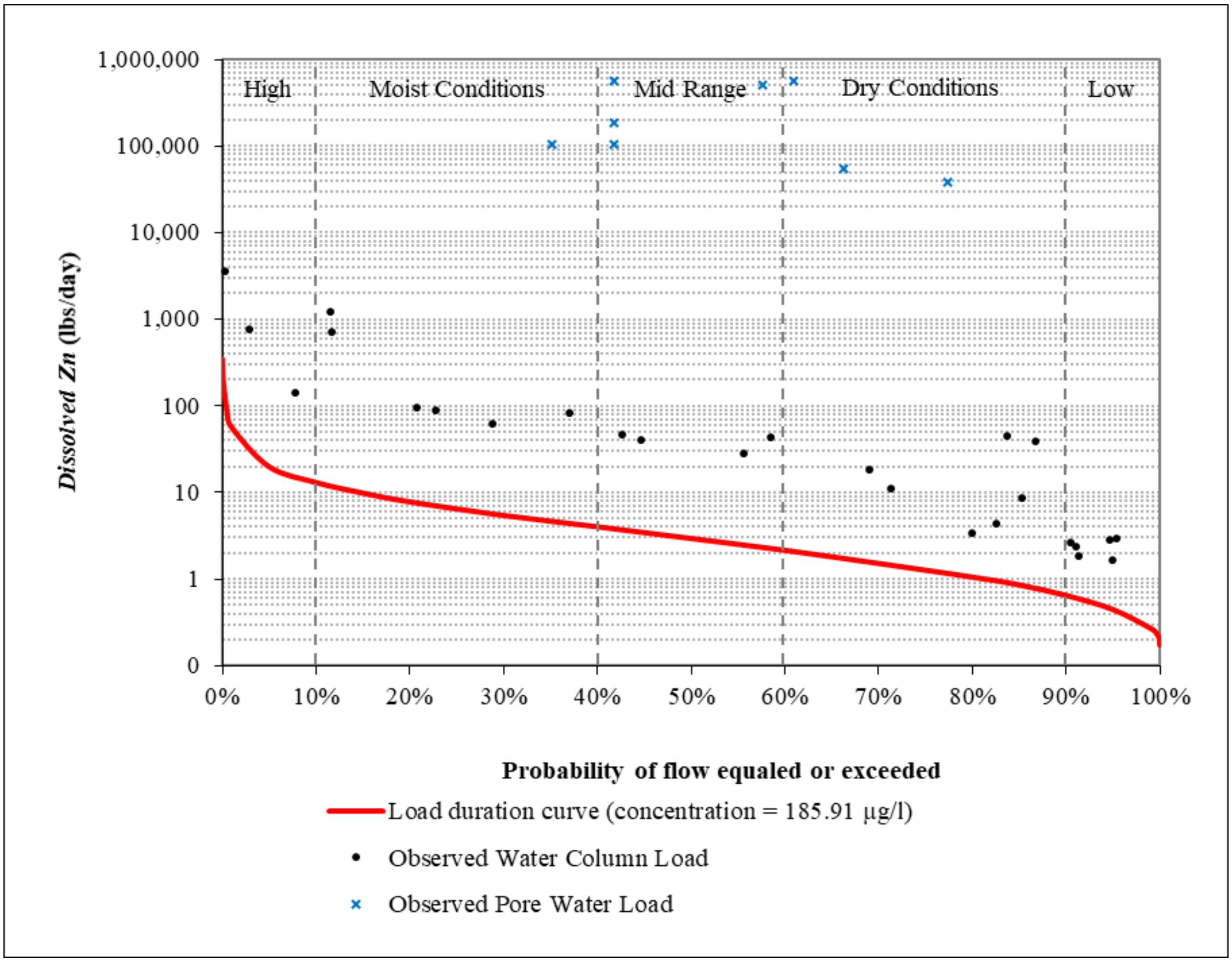

Figure 15. Dissolved zinc TMDL for Bens Branch, water body ID 3980.

Table 25. Dissolved zinc TMDL and allocation values for Bens Branch (WBID 3980) at selected flows.

Percent of time flow equaled or exceeded	Flow ft^3/s	TMDL (pounds/day)	∑WLA (pounds/day)	∑LA (pounds/day)	MOS (pounds/day)
95	0.5	0.45	0.33	0.08	0.05
75	1.3	1.26	0.92	0.22	0.13
50	3.0	2.97	2.16	0.51	0.30
25	6.5	6.49	4.72	1.12	0.65
5	19.8	19.80	14.40	3.42	1.98

8. Wasteload Allocation (Point Source Load)

The wasteload allocation is the allowable amount of the loading capacity assigned to existing or future point sources. This section discusses the rationale and approach for assigning metals wasteload allocations to point sources in the Center Creek watershed as well as considerations given for future sources. Typically, point source permit limits for a given pollutant are the most stringent of either technology-based effluent limits or water quality-based effluent limits. Technology-based effluent limits are based upon the expected capability of a treatment method to reduce the pollutant to a certain concentration. Water quality-based effluent limits represent the most stringent concentration of a pollutant a receiving stream can assimilate without violating applicable water quality standards at a specific location. Per 40 CFR 122.44(d)(1)(vii)(B), effluent limits or other permit conditions must be consistent with the assumptions and requirements of TMDL wasteload allocations. How these conditions are expressed can vary depending upon the pollutant and nature of the discharge. Although TMDLs are required to be written for daily time increments, permit effluent limits may be written in a form that derives from and complies with applicable water quality standards that use any time measure (40 CFR 122.44(d)(1)(vii)(A) and EPA 2006). The Department's permit writers have discretion for how TMDL wasteload allocations are expressed in a permit and for determining appropriate implementation schedules. Although wasteload allocations are often specified for individual facilities, in some cases, it may be appropriate for pollutant loadings to be shifted between the individual facilities during permitting as long as the sum of the wasteload allocations remains unchanged and is not exceeded.

The wasteload allocations presented in this TMDL report do not preclude the establishment of future point sources. Any future point sources should be evaluated against the TMDL, the range of flows with which any additional metals loading will affect, and any additional requirements associated with antidegradation. Per federal regulations at 40 CFR 122.4(a), no permit may be issued when the conditions of the permit do not provide for compliance with the applicable requirements of the federal Clean Water Act, or regulations promulgated under the federal Clean Water Act. Additionally, 40 CFR 122.4(i) states no permit may be issued to a new source or new discharger if the discharge from its construction or operation will cause or contribute to violation of water quality standards. After undergoing antidegradation review, any new facility that discharges wastewater containing specified metals should operate in a manner that will not result in loading greater than the established wasteload allocations.

8.1 Domestic Wastewater Facilities

The aggregated wasteload allocation for domestic wastewater dischargers in the Center Creek watershed is 0.06 lbs/day for dissolved cadmium and 0.25 lbs/day for dissolved lead at all flows. The aggregated wasteload allocations for site-specific permitted domestic wastewater dischargers is based on the sum of individual facility design flows and applicable TMDL targets. Wasteload allocations calculated for existing domestic wastewater dischargers are based on design flow instead of actual flow and will account for future discharge increases. There are no domestic wastewater dischargers in the subwatersheds of Bens Branch and Center Creek tributary.

Although domestic wastewater dischargers are not expected to cause or contribute to the sediment toxicity impairments of Center Creek, TMDL targets are based on attainment of dissolved metals criteria in pore water. Therefore a wasteload allocation is being provided. Because Center Creek is not impaired for dissolved cadmium or dissolved lead, it is assumed that existing loading from permitted facilities is consistent with the given wasteload allocations and no pollutant reductions from these facilities are necessary as a result of this TMDL. The wasteload allocations in this TMDL report do not authorize any facility to discharge cadmium or lead at concentrations that exceed water quality standards. Facilities found to have reasonable potential to violate water quality standards should be given effluent limits appropriate to meet water quality standards in Center Creek, but at no time should the sum of the wasteload allocation be exceeded.

8.2 Industrial and Commercial Facilities

There are three industrial and commercial permitted wastewater facilities in the Center Creek watershed (Table 13). There are no site-specific permitted industrial and commercial facilities in the subwatersheds of Bens Branch or Center Creek tributary. Wasteload allocations for the Dyno Nobel facility are based on the facility's design flow and applicable dissolved metal targets for Center Creek (Table 26). These wasteload allocations are static and do not vary with flow. The EBV Explosives Environmental facility discharges in response to precipitation events. Stormwater from this facility is addressed through a Stormwater Pollution Prevention Plan and is treated using best management practices. For these reasons, wasteload allocations for the EBV Explosives Environmental facility are set at permit conditions requiring best management practices. Due to extensive remediation and BMP implementation at the Expert Management Incorporated property, this facility is not expected to contribute metal loads above *de minimis* concentrations. For these reasons, the wasteload allocation for the Expert Management Incorporated facility is set at current permit limits and conditions

Table 26. Dissolved cadmium (Cd) and lead (Pb) wasteload allocations for Dyno Nobel.

Facility Name	Facility Permit Number	Facility Design Flow (cfs)	Pollutant	Target Concentration (µg/L)	WLA (lbs/day)
Dyno Nobel	MO-0002402	0.536	Dissolved Cd	1.08	0.0031
			Dissolved Pb	4.52	0.01307

8.3 Abandoned Mine Lands

Abandoned mine lands within the Center Creek watershed are a potential source of metals contamination in nearby water bodies. Abandoned mine areas can contribute pollutant loads to the impaired steams during both dry and wet weather conditions through the re-emergence of groundwater and from surface runoff. For abandoned mine lands wasteload allocations that vary with flow were established based on the proportion of Superfund operational units within the impaired streams' watersheds, specifically the Oronogo-Duenweg Mining Belt superfund footprint (ATSDR, 2010). Table 27 provides the abandoned mine land wasteload allocations for each impaired water body and corresponding contaminant of concern. Daily loads are based on the metals concentration targets presented in this TMDL. Consideration of these concentration targets and wasteload allocations should be included in any Applicable or Relevant and Appropriate Requirements (ARARs) required by CERCLA as part of ongoing superfund remediation.

A Geographic Information System analysis determined abandoned mine lands comprise approximately 9 square miles (3 percent) of the Center Creek watershed, 0.60 square miles (20 percent) of the tributary to Center Creek subwatershed, and 4.5 square miles (71 percent) of the Bens Branch subwatershed.

Table 27. Abandoned mine lands wasteload allocations for impaired waters in the Center Creek watershed.

Pollutant	Percent of time flow is equaled or exceeded	Center Cr. WBID 3203 (lbs/day)[25]	Center Cr. Trib WBID 5003 (lbs/day)	Bens Branch WBID 3980 (lbs/day)
Dissolved Cadmium	95	0.0079	0.0002	0.0018
	75	0.0173	0.0007	0.0051
	50	0.0371	0.0016	0.0121
	25	0.0780	0.0035	0.0265
	5	0.2324	0.0108	0.0807
Dissolved Lead	95	0.0333	0.0010	0.008
	75	0.0724	0.0029	0.022
	50	0.1554	0.0068	0.051
	25	0.3265	0.0148	0.111
	5	0.9725	0.0451	0.338
Dissolved Zinc	95		0.0425	0.318
	75		0.1181	0.885
	50		0.2783	2.085
	25		0.6085	4.559
	5		1.8553	13.900

8.4 Concentrated Animal Feeding Operations

All CAFO facilities in the watershed are permitted as no-discharge facilities and store wastewater in lagoons and land apply according to permit conditions. For this reason, the wasteload allocation for all CAFO facilities is zero at all flows. As stated in Section 5.1.4, CAFO facilities are not expected to be a significant source of metals loading.

8.5 Municipal Separate Storm Sewer Systems

Due to the remediation actions described in Section 5.1.5., discharges from MS4s are not expected to be a significant contributor to the metals impairments in the Center Creek watershed. Although existing pollutant loading from the MS4 is not expected to contribute significant metal loads, due to the large amount of area in the watershed potentially contributing flow to MS4s a numeric wasteload allocation is specified. For this TMDL MS4 wasteload allocations are based on the applicable metals concentration target and the proportion of U.S. Census Bureau urban area present within the impaired stream's watershed, but does not include areas of abandoned mine lands that are contained within Superfund operational units. Table 28 provides aggregated MS4 wasteload allocations for each impaired water body segment and corresponding contaminants of concern.

[25] Wasteload allocations for dissolved cadmium and lead are protective of downstream impaired waters.

Should the defined urban area in the watershed be expanded in the future, then the appropriate portion of the load allocation may be assigned as part of the MS4 wasteload allocation if such a source's magnitude, character, and location remain unchanged. Urban area comprises approximately 25 square miles (8 percent) of the Center creek watershed, 1.1 square miles (37 percent) of tributary to Center Creek subwatershed, and 4.6 square miles (73 percent) of the Bens Branch subwatershed. Existing MS4 permit conditions and continued implementation of the six minimum control measures are expected to be consistent with the assumptions and requirements of the MS4 wasteload allocation.

Table 28. Aggregate MS4 wasteload allocations for the impaired waters in the Center Creek watershed.

Pollutant	Percent of time flow is equaled or exceeded	Center Cr. WBID 3203 (lbs/day)	Center Cr. Trib WBID 5003 (lbs/day)	Bens Branch WBID 3980 (lbs/day)
Dissolved Cadmium	95	0.0151	0.0002	0.00007
	75	0.0328	0.0006	0.00018
	50	0.0703	0.0014	0.00043
	25	0.1477	0.0031	0.00095
	5	0.4400	0.0095	0.00290
Dissolved Lead	95	0.063	0.0009	0.0003
	75	0.137	0.0025	0.0008
	50	0.294	0.0059	0.0018
	25	0.618	0.0130	0.0040
	5	1.841	0.0396	0.0121
Dissolved Zinc	95		0.037	0.011
	75		0.104	0.032
	50		0.244	0.075
	25		0.534	0.164
	5		1.630	0.499

8.6 Other General Wastewater and Stormwater Discharges

Activities that require general or stormwater permits are not typically expected to contribute significant metals loads to surface waters, and permit conditions are protective of the designated uses assigned to all water bodies in the watershed. Activities for which these permits are issued are expected to be conducted in compliance with all permit conditions, including any land application, monitoring, stormwater pollution prevention plans, and discharge limitations. For these reasons, the wasteload allocations for these facilities are set at existing permit limits and conditions. Future general and stormwater permitted activities that operate in full compliance with permit conditions are not expected to contribute metals loading above *de minimis* concentrations and will not result in loading that exceeds the sum of the TMDL wasteload allocations.

9. Load Allocation (Nonpoint Source Load)

The load allocation is the portion of the loading capacity assigned to existing and future nonpoint sources, as well as natural background contributions (40 CFR 130.2(g)). Load allocations for these

TMDLs are calculated as the remainder of the loading capacity after allocations to the wasteload allocations and margins of safety. Load allocations are presented in Tables 16 through 25. No portion of these load allocations are assigned to onsite domestic wastewater treatment systems, as such systems should not be contributing significant metals loads when operating as designed and properly maintained. For this reason, onsite wastewater treatment systems are assigned a load allocation of zero at all flows. As stated in Section 5.2, current land cover conditions in the Center Creek watershed likely inhibit overland contributions of metals loading via runoff or erosion and these sources are not expected to contribute significant metal loads.[26] However, any potential metal contributions from these areas are considered within the total load allocation. The load allocation also accounts for potential resuspension of metals from instream sediments that may result during precipitation and high flow events.

10. Margin of Safety

A margin of safety is required to account for uncertainties in scientific and technical understanding of water quality in natural systems (CWA Section 303(d)(l)(C) and 40 CFR 130.7(c)(l)). Based on EPA guidance, the margin of safety can be achieved through two approaches:

- Explicit - Reserve a portion of the loading capacity as a separate term in the TMDL.
- Implicit - Incorporate the margin of safety as part of the critical conditions for the wasteload allocation and the load allocation calculations by making conservative assumptions in the analysis.

An explicit margin of safety equal to 10 percent of the loading capacity is included in the TMDLs. Additionally, metals chelation, and transformation rates were not applied. These conservative assumptions serve as an additional implicit margin of safety. Furthermore, dissolved metals targets applicable to the pore water environment result in sediment concentration targets below consensus-based Threshold Effect Concentrations and provides an additional implicit margin of safety. Threshold Effect Concentrations are less than the PEC values the Department considers for impairment listing decisions.[27] The use of low soil pH values and equilibrium partitioning coefficients, as described in Section 7, results in conservative estimates of needed pollutant reductions and provides additional assurances that the selected TMDL targets are adequately protective of aquatic life.

11. Seasonal Variation

Federal regulations at 40 CFR 130.7(c)(1) require that TMDLs take into consideration seasonal variation in applicable water quality standards. Missouri's water quality criteria for the protection of warm water habitat (aquatic life) uses are applicable during all seasons. The load duration curves provide metals loading capacities for each water body at all possible flow regimes using numerous years of flow data collected during all seasons. For this reason, the load duration curve approach ensures all critical conditions are appropriately considered and protected.

[26] The presence and type of vegetated land use located specifically in mining areas of the Oronogo Duenweg Mining Belt can be determined through comparison of Figures 6 and 7.

[27] As stated in Section 3.2.1, the Department judges a stream to be impaired if metals sediment concentrations are 150 percent greater than PEC values.

12. Monitoring Plans

The Department conducts water quality monitoring in impaired waters within a reasonable timeframe following the approval of TMDLs, completion of facility upgrades and permit compliance schedules, or the implementation of watershed BMPs. The Department will also routinely examine quality-assured water quality data collected by other local, state, and federal entities in order to assess the effectiveness of TMDL implementation. Currently the Department funds USGS monitoring location number 07186480 Center Creek near Smithfield which is monitored three times per year for metals and six times per year for total residue, which includes suspended solids. In addition, certain quality-assured data collected by universities, municipalities, private companies, and volunteer groups may potentially be considered for monitoring water quality following TMDL implementation.

13. Reasonable Assurance

Section 303(d)(1)(C) of the federal Clean Water Act requires that TMDLs be established at a level necessary to implement applicable water quality standards. As part of the TMDL process, consideration must be given to the assurances that point and nonpoint source allocations will be achieved and water quality standards attained. Where TMDLs are developed for waters impaired by point sources only, reasonable assurance is provided through the National Pollutant Discharge Elimination System (NPDES) permitting program. State operating permits requiring effluent and instream monitoring being reported to the Department provides reasonable assurance that instream water quality standards will be met.

Where a TMDL is developed for waters impaired by both point and nonpoint sources, point source wasteload allocations must be stringent enough so that in conjunction with the water body's other loadings (i.e., nonpoint sources) water quality standards are met. Reasonable assurance that nonpoint sources will meet their allocated amount is dependent upon the availability and implementation of nonpoint source pollutant reduction plans, controls, or BMPs within the watershed. If best management practices or other nonpoint source pollution controls allow for more stringent load allocations, then wasteload allocations can be less stringent. Thus, the TMDL process provides for nonpoint source control tradeoffs (40 CFR 130.2(i)). When a demonstration of nonpoint source reasonable assurance is developed for an impaired water body, additional pollutant allocations for point sources may be allowed provided water quality standards are still attained. If a demonstration of nonpoint source reasonable assurance does not exist, or it is determined that nonpoint source pollutant reduction plans, controls, or BMPs are not feasible, durable, or will not result in the required load reductions, then allocation of greater pollutant loading to point sources cannot occur.

A variety of grants and loans may be available to assist watershed stakeholders with developing and implementing watershed based plans, controls, and practices to meet the required wasteload and load allocations in the TMDL and demonstrate reasonable assurance. Information regarding potential funding sources and implementation actions addressing pollutant sources in the Center Creek watershed is provided in the supplemental TMDL Implementation Strategies document at dnr.mo.gov/water/what-were-doing/water-planning/quality-standards-impaired-waters-total-maximum-daily-loads/tmdls.

14. Public Participation

EPA regulations at 40 CFR 130.7 require that TMDLs be subject to public review. A 45-day public notice period for this TMDL report was held from July 16 through August 30, 2021. No public comments were received.

Groups that directly received notice of the public comment period for this TMDL include, but are not limited to:

- Missouri Clean Water Commission;
- Missouri Water Protection Forum;
- Missouri Department of Conservation;
- U.S. Fish and Wildlife Service
- Harry S. Truman Coordinating Council
- County soil and water conservation districts;
- Jasper, Newton, and Lawrence County health departments;
- County commissions;
- University of Missouri Extension;
- Missouri Coalition for the Environment;
- Stream Teams United;
- Stream Team volunteers living in or near the watershed;
- Affected permitted entities; and
- Missouri state legislators representing areas within the watershed.

In addition to those groups directly contacted about the public notice, this TMDL report and an implementation strategies document are posted on the Department's TMDL webpage at dnr.mo.gov/water/what-were-doing/water-planning/quality-standards-impaired-waters-total-maximum-daily-loads/tmdls. All comments received during the public notice period and the Department's responses to those comments are also posted at this location.

The Department also maintains an email distribution list for notifying subscribers of significant TMDL updates or activities, including public notices and comment periods. Those interested in subscribing to TMDL updates can submit their email address using the online form available at public.govdelivery.com/accounts/MODNR/subscriber/new?topic_id=MODNR_177.

15. Administrative Record and Supporting Documentation

The Department has an administrative record on file for this Center Creek metals TMDL. The record contains any plans, studies, data, and calculations on which the TMDL is based. It additionally includes the TMDL implementation strategies document, the public notice announcement, any public comments received, and the Department's responses to those comments. This information is available upon request to the Department at dnr.mo.gov/open-records-sunshine-law-requests. Any request for information about this TMDL will be processed in accordance with Missouri's Sunshine Law (Chapter 610, RSMO) and the Department's administrative policies and procedures governing Sunshine Law requests.

16. References

Andrews, W.J., M.F. Becker, S.L. Mashburn, and S.J. Smith. 2009. Selected metals in sediments and streams in the Oklahoma part of the Tri-State mining district. U.S. Geological Survey Scientific Investigations Report. SIR 2009-5032. [Online WWW] Available URL: http://pubs.usgs.gov/sir/2009/5032/ [Accessed 31 August 2020].

Anthony Arguez, Imke Durre, Scott Applequist, Mike Squires, Russell Vose, Xungang Yin, and Rocky Bilotta 2010. NOAA's U.S. Climate Normals (1981-2010). [indicate subset used]. NOAA National Centers for Environmental Information. DOI:10.7289/V5PN93JP, access date: 03/25/2020.

Arnold, C.L. and C.J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association 62.2

ATSDR (Agency for Toxic Substances and Disease Registry). 2010. ATSDR Hazardous Waste Site Polygon Data, Version 2. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H48P5XF7. [Accessed 12 July 2020].

Barks, J.H. 1977, Effects of abandoned lead and zinc mines and mine-waste piles on water quality in the Joplin area, Missouri: U.S. Geological Survey Water-Resources Investigations 77–75, 49 p.

Barrak, M. A. New trends in removing heavy metals from industrial wastewater. Arabian Journal of Chemistry 4, p.361–377

Brown, E., Caraco, D. and R. Pitt. 2004. Illicit Discharge Detection and Elimination a Guidance Manual for Program Development and Technical Assessments. EPA X-82907801-0

Burton, A.G. Jr. and R.E. Pitt. 2002. Stormwater effects handbook, a toolbox for watershed managers, scientists, and engineers. ISBN 0-87371-924-7 New York:CRC Press.

Chapman, S.S., Omernik, J.M., Griffith, G.E., Schroeder, W.A., Nigh, T.A., and Wilton, T.F. 2002. Ecoregions of Iowa and Missouri (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,800,000).

Cleland, B.R., 2002. TMDL Development From the "Bottom Up" – Part II: Using Load Duration Curves to Connect the Pieces. Proceedings from the WEF National TMDL Science and Policy 2002 Conference.

Cleland, B.R. 2003. TMDL Development from the "Bottom up" – Part III: Duration Curves and Wet-Weather Assessments. America's Clean Water Foundation, Washington, D.C.

DHSS (Missouri Department of Health and Senior Services). 2018. Onsite Wastewater Treatment webpage. [Online WWW] Available URL: health.mo.gov/living/environment/onsite/ [Accessed 15 October 2019].

Hambleton, W.W., Lyden, J.P., and Brockie, D.C. 1959. Geophysical Investigation in the Tri-State Zinc and Lead Mining District. Symposium on Geophysics in Kansas: Kansas Geological Survey, Bulletin 137, p. 357-375

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing*, v. 81, no. 5, p. 345-354 [Online WWW] Available URL: cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=309950 [Accessed 16 May 2018].

Juraeck, K.E., and Becker, M.F., 2009. Occurrence and trends of selected chemical constituents in bottom sediment, Grand Lake O' Cherokees, northeast Oklahoma, 1940-2008: USGS Geological Survey Scientific Investigations Report 2009-5258, 28 p.

Irshad, M., Malik, A.H., Shaukat, S., Mushtaq, S., and Ashraf, M., 2012. Characterization of heavy metals in livestock manures. Pol. J. Environ. Stud. Vol. 22, No. 4 (2013), p. 1257-1262

MacDonald, D.D, Ingersoll, C.G., Berger, T.A. 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ. Contamination Toxicology. 39, p. 20-31.

MoDNR (Missouri Department of Natural Resources), and DOI (The United States Department of Interior), 2002. Preassessment Screen and Determination, Jasper County Superfund Site, Jasper County, Missouri pp 3.

MoRAP (Missouri Resource Assessment Partnership). 2005. A gap analysis for riverine ecosystems of Missouri. Final report, submitted to the USGS national gap analysis program. 1675pp.

NOAA (National Oceanic and Atmospheric Administration). 2020. NOAA Online Weather Data. [Online WWW] Available URL: https://www.ncdc.noaa.gov/cdo-web/datatools/normals [Accessed 12 Sep 2019].

NRCS (Natural Resources Conservation Service). 2020. U.S. Department of Agriculture. [Online WWW] Available URL: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Schueler, Tom. 1994. The importance of imperviousness. Watershed Protection Techniques. 1.3

Sutton, Alan L. 1990. Animal Agriculture's Effect on Water Quality Pastures and Feedlots. WQ-7. Purdue University Extension. [Online WWW]. Available URL: http://www.ces.purdue.edu/extmedia/wq/wq-7.htmL [Accessed 23 Dec. 2011].

U.S. Census Bureau (U.S. Department of Commerce). 2010. TIGER/Line Shapefile, 2010, 2010 state, Missouri, 2010 Census Block State-based [ArcView Shapefile].

USDA (U.S. Department of Agriculture). 1995. Animal Manure Management – RCA Issue Brief #7. [Online WWW] Available URL: nrcs.usda.gov/wps/portal/nrcs/detail/null/?cid=nrcs143_014211 [Accessed 15 May 2018].

USEPA (U.S. Environmental Protection Agency). 1983. Results of the Nationwide Urban Runoff Program – Executive Summary PB84-185545.

USEPA (U.S. Environmental Protection Agency). 1993. Memo: NPDES Permit Issues and Hard Rock Mines. USEPA Region 8, Denver, Colorado

USEPA (U.S. Environmental Protection Agency). 1996. Sanitary Sewer Overflows – What are they and how can we reduce them? EPA 832-K-96-001

USEPA (U.S. Environmental Protection Agency). 1996. The metals translator: guidance for calculating a total recoverable permit limit from a dissolved criterion. Office of Water. EPA 823-B-96-007.

USEPA (U.S. Environmental Protection Agency). 1999. Partition Coefficients for Lead. EPA 402-R-99-004B - Appendix F. EPA Office of Air and Radiation, Washington D.C. https://www.epa.gov/sites/default/files/2015-05/documents/402-r-99-004b.pdf [Accessed 12 Nov. 2021]

USEPA (U.S. Environmental Protection Agency). 2005. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metals Mixtures (Cadmium, Copper, Lead, Nickel, Silver, and Zinc). Available URL: https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHEERL&dirEntryId=130408 [Accessed 11 March 2020]

USEPA (U.S. Environmental Protection Agency). 2006. Establishing TMDL "daily" loads in light of the decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006), and implications for NPDES Permits. [Online WWW] Available URL: www.epa.gov/tmdl/impaired-waters-and-tmdls-tmdl-information-and-support-documents [Accessed 15 May 2018].

USEPA (U.S. Environmental Protection Agency). 2007a. Options for Expressing Daily Loads in TMDLs. Office of Wetlands, Oceans & Watersheds. June 22, 2007.

USEPA (U.S. Environmental Protection Agency). 2007b. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006.

USEPA (U.S. Environmental Protection Agency). 2014a. Environmental Justice [Online WWW] Available URL: www.epa.gov/environmentaljustice [Accessed 6 March 2020].

USEPA (U.S. Environmental Protection Agency). 2014b. STEPL Data Server for Sample Input Data. [Online WWW] Available URL: it.tetratech-ffx.com/steplweb/STEPLdataviewer.htm [Accessed 16 May 2018].

USEPA (U.S. Environmental Protection Agency). 2017. Fourth Five-Year Review Report for Oronogo-Duenweg Mining Belt Superfund Site Jasper County, Missouri. Region 7, Lenexa KS. Available URL: https://semspub.epa.gov/work/07/30323583.pdf

USEPA (U.S. Environmental Protection Agency). 2020. National priorities list sites in Missouri. [Online WWW] Available URL: https://www.epa.gov/superfund/superfund-national-priorities-list-npl [Accessed 10 March 2020]

USGS (U.S. Geological Survey) and NRCS (Natural Resources Conservation Service). 2013. Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD) (4th ed): US Geological Survey Techniques and Methods 11-A3, 63p. Available URL: pubs.usgs.gov/tm/11/a3/

USGS (U.S. Geological Survey). 2009. Ecology-Ecological Drainage Units. [Online WWW] Available URL: nh.water.usgs.gov/projects/ct_atlas/tnc_edu.htm [Accessed 7 June 2017].

USGS (U.S. Geological Survey). 2019. Hydrologic Unit Maps. [Online WWW] Available URL: https://water.usgs.gov/GIS/huc.html [Accessed 2019]. (FGDC 2003) reference is Federal Geographic Data Committee (FGDC). 2003. FGDC Proposal, Version 1.1, Federal Standards for Delineation of Hydrologic Unit Boundaries. December 23, 2003.

Schaider, L.A., Senn, D.B., Brabander, D.J., McCarthey, K.D., and Shine, J.P. 2007. Characterization of zinc, lead, and cadmium in mine waste – Implications for transport, exposure, and bioavailability: Environmental Science and Technology, v. 41, p. 4,164-4,171

Schwartz, M. O. 2000. Cadmium in Zinc Deposits: Economic Geology of a Polluting Element. International Geology Review. Vol. 42. 2000. p. 445-469.

Appendix A: Center Creek Watershed Water Quality Data

Table A1. Center Creek Sediment Cadmium Data

Water body	Sampling Organization[28]	Sample ID	Site Code	Sample Type	Date	Sediment Cadmium (mg/kg)
Center Creek WBID 3203	USGS	183674	3203/1.0	Grab	3/1/1976	20
	USGS	183687	3203/26.6	Grab	3/1/1976	5
	USGS	235187	3203/1.0	Grab	3/10/1976	20
	USGS	235197	3203/26.6	Grab	3/10/1976	5
	USGS	236537	3203/19.5	Grab	12/20/1977	4
	DM	183396	3203/2.5	Grab	12/1/1995	12
	DM	183394	3203/1.0	Grab	12/1/1995	6
	DM	183395	3203/10.0	Grab	12/1/1995	68
	DM	183397	3203/24	Grab	12/1/1995	0.6
	MDNR	184273	3203/9.0	Grab	8/1/2001	89.2
	MDNR	184271	3203/2.5	Grab	8/12/2003	10.5
	BV	228221	3203/2.5	Grab	5/1/2006	12.5
	BV	228225	3203/4.5	Grab	5/1/2006	10.9
	BV	228219	3203/15.6	Grab	5/2/2006	6.74
	BV	228212	3203/1.0	Grab	5/2/2006	32
	BV	228218	3203/12.9	Grab	5/2/2006	9.87
	BV	228217	3203/12.7	Grab	5/2/2006	28.8
	BV	228226	3203/6.5	Grab	5/2/2006	3.28
	BV	228227	3203/6.8	Grab	5/2/2006	55.8
	BV	228220	3203/15.8	Grab	5/2/2006	2.12
	BV	228213	3203/10.9	Grab	5/3/2006	51.2
	BV	228214	3203/10.0	Grab	5/3/2006	44.4
	BV	228215	3203/11.6	Grab	5/3/2006	58.9
	BV	228228	3203/9.8	Grab	5/3/2006	62.4
	BV	228224	3203/26.6	Grab	5/3/2006	0.74
	BV	228223	3203/21.25	Grab	5/3/2006	0.62
	BV	228210	3203/0.1	Grab	5/5/2006	1.45
	BV	228211	3203/0.1	Grab	5/5/2006	26.9
	BV	228222	3203/21.3	Grab	5/17/2006	2.07
	USGS-BRD	228188	3203/12.9	Grab	8/20/2007	17.7
	USGS-BRD	228186	3203/11.6	Grab	8/20/2007	25.8
	USGS-BRD	228185	3203/10.9	Grab	8/21/2007	38.25
	USGS-BRD	228184	3203/1.0	Grab	8/21/2007	26.95
	USGS-BRD	228189	3203/15.9	Grab	8/21/2007	14.3

[28] USGS = United States Geological Survey (USGS); DM = Dames and Moore Inc.; MDNR = Missouri Department of Natural Resources; USGS-BRD = USGS Biological Research Division; BV = Black and Veatch Inc.

Water body	Sampling Organization[28]	Sample ID	Site Code	Sample Type	Date	Sediment Cadmium (mg/kg)
Center Creek WBID 3203	USGS-BRD	228190	3203/6.8	Grab	8/21/2007	14.3
	MDNR	251426	3203/20.7	CompWOP[29]	9/16/2014	0.737
	MDNR	251430	3203/8.5	CompWOP	9/16/2014	72.1
	MDNR	251428	3203/24.9	CompWOP	9/16/2014	0.428
	MDNR	251424	3203/2.5	CompWOP	9/17/2014	26.8
	MDNR	251422	3203/12.9	CompWOP	9/17/2014	4.19
	MDNR	251420	3203/12.7	CompWOP	9/17/2014	46.6
	MDNR	256194	3203/20.7	Grab	10/6/2015	2.55
	MDNR	256198	3203/8.5	Grab	10/6/2015	11.4
	MDNR	256196	3203/24.9	Grab	10/6/2015	0.973
	MDNR	256192	3203/2.5	Grab	10/7/2015	8.94
	MDNR	256190	3203/12.9	Grab	10/7/2015	5.61
	MDNR	256188	3203/12.7	Grab	10/7/2015	13.5

Table A2. Center Creek Sediment Lead Data

Water Body	Sampling Organization[30]	Sample ID	Site Code	Sample Type	Date	Sediment Lead (mg/kg)
Center Creek WBID 3203	USGS	183674	3203/1.0	Grab	3/1/1976	350
	USGS	183687	3203/26.6	Grab	3/1/1976	5
	USGS	235187	3203/1.0	Grab	3/10/1976	350
	USGS	235197	3203/26.6	Grab	3/10/1976	5
	USGS	183685	3203/2.5	Grab	9/1/1976	220
	USGS	183682	3203/15.6	Grab	9/1/1976	400
	USGS	183675	3203/1.0	Grab	9/1/1976	200
	USGS	183677	3203/10.0	Grab	9/1/1976	320
	USGS	183686	3203/24	Grab	9/1/1976	20
	USGS	183684	3203/21.5	Grab	9/1/1976	18
	USGS	183683	3203/21.3	Grab	9/1/1976	20
	USGS	183681	3203/12.9	Grab	9/1/1976	200
	USGS	183680	3203/12.7	Grab	9/1/1976	400
	USGS	183689	3203/6.5	Grab	9/1/1976	450
	USGS	183676	3203/19.5	Grab	9/1/1976	20
	USGS	183688	3203/26.6	Grab	9/1/1976	20
	USGS	235196	3203/24	Grab	9/20/1976	20
	USGS	235198	3203/26.6	Grab	9/20/1976	20
	USGS	235192	3203/15.6	Grab	9/21/1976	400

[29] Composite sample without parent.

[30] EE = Ecology and Environment Inc.

Water Body	Sampling Organization[30]	Sample ID	Site Code	Sample Type	Date	Sediment Lead (mg/kg)
Center Creek WBID 3203	USGS	235195	3203/21.5	Grab	9/21/1976	18
	USGS	235194	3203/21.3	Grab	9/21/1976	20
	USGS	235191	3203/12.9	Grab	9/21/1976	200
	USGS	235190	3203/12.7	Grab	9/21/1976	400
	USGS	235193	3203/19.5	Grab	9/21/1976	20
	USGS	235188	3203/1.0	Grab	9/22/1976	200
	USGS	235200	3203/6.5	Grab	9/22/1976	450
	USGS	235199	3203/4.5	Grab	9/22/1976	220
	USGS	235201	3203/8.5	Grab	9/22/1976	320
	USGS	236537	3203/19.5	Grab	12/20/1977	30
	EE	183812	3203/11.0/0.5	Grab	2/1/1986	7300
	EE	183814	3203/11/0.7	Grab	2/1/1986	4800
	EE	183811	3203/10.0	Grab	2/1/1986	2000
	EE	183818	3203/12.7	Grab	2/1/1986	2800
	DM	183396	3203/2.5	Grab	12/1/1995	166
	DM	183394	3203/1.0	Grab	12/1/1995	99
	DM	183395	3203/10.0	Grab	12/1/1995	242
	DM	183397	3203/24	Grab	12/1/1995	17
	MDNR	184273	3203/9.0	Grab	8/1/2001	834
	MDNR	184271	3203/2.5	Grab	8/12/2003	147
	BV	228221	3203/2.5	Grab	5/1/2006	135
	BV	228225	3203/4.5	Grab	5/1/2006	227
	BV	228219	3203/15.6	Grab	5/2/2006	99.6
	BV	228212	3203/1.0	Grab	5/2/2006	298
	BV	228218	3203/12.9	Grab	5/2/2006	198
	BV	228217	3203/12.7	Grab	5/2/2006	194
	BV	228227	3203/6.8	Grab	5/2/2006	214
	BV	228226	3203/6.5	Grab	5/2/2006	25.4
	BV	228220	3203/15.8	Grab	5/2/2006	80.1
	BV	228213	3203/10.9	Grab	5/3/2006	428
	BV	228214	3203/10.0	Grab	5/3/2006	355
	BV	228215	3203/11.6	Grab	5/3/2006	305
	BV	228228	3203/9.8	Grab	5/3/2006	417
	BV	228224	3203/26.6	Grab	5/3/2006	16.2
	BV	228223	3203/21.25	Grab	5/3/2006	12.9
	BV	228210	3203/0.1	Grab	5/5/2006	20
	BV	228211	3203/0.1	Grab	5/5/2006	207
	BV	228222	3203/21.3	Grab	5/17/2006	113
	USGS-BRD	228188	3203/12.9	Grab	8/20/2007	194

Water Body	Sampling Organization[30]	Sample ID	Site Code	Sample Type	Date	Sediment Lead (mg/kg)
Center Creek WBID 3203	USGS-BRD	228186	3203/11.6	Grab	8/20/2007	268
	USGS-BRD	228185	3203/10.9	Grab	8/21/2007	580.5
	USGS-BRD	228184	3203/1.0	Grab	8/21/2007	378
	USGS-BRD	228189	3203/15.9	Grab	8/21/2007	38.7
	USGS-BRD	228190	3203/6.8	Grab	8/21/2007	311
	MDNR	251426	3203/20.7	CompWOP	9/16/2014	23.9
	MDNR	251430	3203/8.5	CompWOP	9/16/2014	571
	MDNR	251428	3203/24.9	CompWOP	9/16/2014	12
	MDNR	251424	3203/2.5	CompWOP	9/17/2014	292
	MDNR	251422	3203/12.9	CompWOP	9/17/2014	119
	MDNR	251420	3203/12.7	CompWOP	9/17/2014	233
	MDNR	256194	3203/20.7	Grab	10/6/2015	36.6
	MDNR	256198	3203/8.5	Grab	10/6/2015	167
	MDNR	256196	3203/24.9	Grab	10/6/2015	16.8
	MDNR	256192	3203/2.5	Grab	10/7/2015	117
	MDNR	256190	3203/12.9	Grab	10/7/2015	110
	MDNR	256188	3203/12.7	Grab	10/7/2015	102

Table A3. Center Creek Hardness Data

Date	Hardness (Ca, Mg) mg/L	Sample Count	Date	Hardness (Ca, Mg) mg/L	Sample Count	Date	Hardness (Ca, Mg) mg/L	Sample Count	Date	Hardness (Ca, Mg) mg/L	Sample Count
9/5/1973	47	1	1/6/1975	130	51	9/25/1968	143	101	6/9/1969	157	151
5/23/1978	57	2	4/4/1975	130	52	10/6/1970	143	102	5/10/1983	157	152
4/8/1986	68	3	6/10/1975	130	53	12/3/1985	143	103	1/8/1985	157	153
3/20/1968	73	4	4/16/1980	130	54	4/16/1968	144	104	5/2/2016	157	154
5/17/2010	74.1	5	4/4/1984	130	55	2/16/1965	145	105	1/17/1968	158	155
5/23/1978	76	6	4/6/1988	130	56	5/14/1969	146	106	8/3/1970	158	156
5/18/1993	87	7	1/4/1989	130	57	1/10/1984	147	107	6/12/1990	158	157
6/26/1968	90	8	11/16/1993	130	58	11/15/1967	149	108	7/7/2011	158	158
5/24/1978	93	9	5/10/1993	131	59	5/15/1968	150	109	5/13/2013	158	159
7/5/1983	93	10	2/13/1968	132	60	7/7/1969	150	110	6/3/1971	160	160
5/9/1993	93	11	12/5/1968	132	61	12/1/1970	150	111	7/14/1971	160	161
4/9/1986	100	12	4/2/1985	134	62	4/7/1971	150	112	1/5/1972	160	162
5/10/1993	104	13	5/9/1993	134	63	5/5/1971	150	113	10/3/1972	160	163
5/25/2011	105	14	1/7/1969	135	64	8/9/1973	150	114	2/15/1973	160	164
1/5/1971	110	15	3/4/1969	135	65	7/8/1974	150	115	6/13/1973	160	165
3/14/1973	110	16	9/1/1964	138	66	8/7/1974	150	116	10/4/1973	160	166
4/10/1973	110	17	4/21/1969	138	67	10/2/1974	150	117	4/3/1975	160	167
12/6/1973	110	18	7/18/1968	139	68	12/9/1974	150	118	3/10/1976	160	168
6/10/1974	110	19	2/2/1971	140	69	12/20/1977	150	119	2/8/1978	160	169
4/4/1984	110	20	12/15/1972	140	70	7/12/1978	150	120	4/4/1979	160	170
4/9/1986	110	21	1/16/1973	140	71	10/11/1978	150	121	1/9/1980	160	171
9/15/1993	110	22	4/10/1973	140	72	10/3/1979	150	122	4/15/1980	160	172
9/2/1964	118	23	7/11/1973	140	73	10/21/1981	150	123	7/1/1980	160	173
4/5/1983	118	24	10/5/1973	140	74	7/7/1982	150	124	10/7/1982	160	174
5/2/1972	120	25	1/7/1974	140	75	7/10/1985	150	125	1/9/1985	160	175
11/15/1972	120	26	5/14/1974	140	76	1/9/1986	150	126	4/17/1985	160	176
3/18/1974	120	27	9/4/1974	140	77	10/15/1986	150	127	7/9/1986	160	177
6/10/1974	120	28	2/3/1975	140	78	7/8/1987	150	128	1/11/1988	160	178
11/11/1974	120	29	5/13/1975	140	79	1/11/1988	150	129	7/13/1988	160	179
2/3/1975	120	30	7/7/1975	140	80	10/6/1993	150	130	1/5/1989	160	180
3/5/1975	120	31	5/16/1978	140	81	6/16/1994	150	131	4/4/1989	160	181
3/10/1976	120	32	6/1/1978	140	82	6/22/1995	150	132	8/23/1993	160	182
4/6/1983	120	33	1/12/1983	140	83	5/22/2002	150	133	12/7/1993	160	183
7/6/1983	120	34	4/6/1983	140	84	7/23/2002	150	134	3/8/1994	160	184
6/22/1993	120	35	7/6/1983	140	85	5/5/2008	150	135	7/13/1994	160	185
6/22/1965	121	36	1/5/1984	140	86	7/8/2008	150	136	8/17/1994	160	186
12/19/1967	123	37	4/10/1984	140	87	10/11/1967	152	137	2/7/1995	160	187
5/10/1993	123	38	7/12/1984	140	88	2/5/2002	152.485	138	4/4/1995	160	188
2/5/1969	125	39	1/10/1985	140	89	8/15/1968	153	139	5/22/1995	160	189
4/10/1990	125	40	4/17/1985	140	90	5/16/2017	153	140	7/14/1995	160	190
6/22/1965	128	41	1/7/1987	140	91	6/4/2002	153.912	141	5/15/2007	160	191
5/4/2006	128	42	4/8/1987	140	92	8/4/1970	154	142	4/12/2010	160	192
11/4/1970	130	43	4/6/1988	140	93	3/12/1985	154	143	6/9/2015	160	193
3/2/1971	130	44	4/4/1989	140	94	3/8/1988	154	144	3/12/2018	160	194
2/14/1973	130	45	7/12/1993	140	95	8/14/1969	155	145	2/4/1969	161	195
5/15/1973	130	46	5/13/2003	140	96	4/12/1988	155	146	9/8/1993	162	196
6/11/1973	130	47	11/30/1964	141	97	4/4/1989	155	147	5/2/2006	162	197
2/4/1974	130	48	6/23/1965	141	98	6/18/2013	155	148	5/17/2006	162	198
4/16/1974	130	49	3/14/1989	141	99	9/8/1993	156	149	6/23/1965	163	199
12/9/1974	130	50	11/13/1968	142	100	5/5/2006	156	150	10/23/1968	164	200

Date	Hardness (Ca, Mg) mg/L	Sample Count	Date	Hardness (Ca, Mg) mg/L	Sample Count	Date	Hardness (Ca, Mg) mg/L	Sample Count	Date	Hardness (Ca, Mg) mg/L	Sample Count
9/1/1994	164	201	5/11/2004	170	251	8/5/1974	180	301	9/8/1993	186	351
5/2/2006	164	202	11/15/2004	170	252	7/24/1979	180	302	5/6/1986	187	352
10/19/2009	164	203	7/11/2007	170	253	7/14/1981	180	303	5/20/2014	187	353
4/12/2010	164	204	4/12/2010	170	254	4/14/1982	180	304	7/29/2015	187	354
9/8/1993	165	205	4/13/2011	170	255	6/5/1984	180	305	11/30/1964	188	355
5/2/2006	165	206	2/3/2016	170	256	7/12/1984	180	306	4/14/1987	188	356
5/3/2006	165	207	9/10/2018	170	257	10/16/1986	180	307	8/11/1987	188	357
4/12/2010	165	208	10/6/2015	171	258	10/6/1987	180	308	10/17/2013	188	358
7/12/2010	165	209	7/18/2017	171	259	9/8/1993	180	309	7/12/1988	189	359
6/4/1985	166	210	12/5/1968	172	260	9/19/1994	180	310	7/11/1989	189	360
5/2/2006	166	211	8/3/1970	172	261	11/2/1994	180	311	7/15/2009	189	361
5/2/2006	166	212	11/30/1982	172	262	3/2/1995	180	312	5/13/2015	189	362
12/6/1983	167	213	5/17/1988	172	263	5/17/2000	180	313	5/22/2018	189	363
3/13/1984	167	214	10/15/2012	172	264	7/25/2000	180	314	6/23/1965	190	364
1/7/1986	167	215	9/16/2014	172	265	9/21/2000	180	315	4/24/1969	190	365
1/12/1988	167	216	9/17/2014	172	266	5/22/2001	180	316	4/6/1971	190	366
10/6/2015	167	217	10/7/2015	172	267	7/21/2003	180	317	8/10/1971	190	367
6/7/2017	167	218	8/9/1988	173	268	7/21/2004	180	318	10/5/1971	190	368
4/2/2002	167.783	219	5/10/1993	173	269	5/24/2005	180	319	4/11/1972	190	369
5/7/1985	168	220	4/4/2006	173	270	5/24/2006	180	320	6/8/1972	190	370
5/3/2006	168	221	5/21/2009	173	271	8/8/2006	180	321	8/9/1973	190	371
11/6/1984	169	222	7/19/2010	173	272	1/19/2010	180	322	7/1/1980	190	372
3/25/2014	169	223	7/29/2013	173	273	5/13/2014	180	323	4/15/1981	190	373
8/6/2002	169.374	224	9/16/2014	173	274	6/24/2014	180	324	7/9/1986	190	374
12/15/1972	170	225	9/17/2014	173	275	12/4/1990	181	325	1/7/1987	190	375
12/3/1973	170	226	10/7/2015	173	276	5/2/2006	181	326	6/14/1988	190	376
4/17/1974	170	227	2/9/1988	174	277	2/8/1983	182	327	7/13/1988	190	377
6/10/1975	170	228	3/22/2017	174	278	2/7/1984	182	328	8/15/1989	190	378
1/20/1982	170	229	8/14/1990	175	279	12/6/1988	182	329	10/5/1994	190	379
7/7/1982	170	230	4/14/2015	175	280	9/8/1993	182	330	11/2/1999	190	380
1/12/1983	170	231	10/8/2002	175.707	281	10/25/2011	182	331	11/5/2002	190	381
10/19/1983	170	232	8/4/1970	176	282	4/11/2012	182	332	7/8/2003	190	382
5/8/1984	170	233	8/4/1970	176	283	10/6/2015	182	333	7/25/2005	190	383
10/4/1984	170	234	2/12/1985	176	284	10/4/2017	182	334	7/24/2006	190	384
7/10/1985	170	235	1/10/1989	176	285	7/24/2018	182	335	10/4/2010	190	385
10/10/1985	170	236	6/15/2016	176	286	10/3/2006	183	336	10/21/2013	190	386
1/9/1986	170	237	2/17/1965	177	287	1/19/2010	183	337	2/10/2014	190	387
2/4/1986	170	238	9/3/1969	177	288	9/8/1982	184	338	8/11/2014	190	388
4/8/1987	170	239	6/9/1982	177	289	7/10/1984	184	339	6/4/2018	190	389
10/5/1988	170	240	6/7/1983	177	290	10/21/1986	184	340	7/7/1982	192	390
4/27/1993	170	241	8/5/1986	177	291	2/2/1987	184	341	8/11/1982	192	391
1/5/1994	170	242	12/4/1984	178	292	3/10/1987	184	342	8/2/1983	192	392
2/11/1994	170	243	6/6/2006	178	293	12/8/1987	184	343	9/6/1983	192	393
4/6/1994	170	244	10/17/2011	178	294	9/26/1994	184	344	6/3/1986	192	394
5/23/1994	170	245	7/9/1985	179	295	5/21/2014	184	345	5/2/2006	192	395
12/8/1994	170	246	5/9/1989	179	296	9/10/2014	184	346	12/3/2002	192.814	396
1/11/1995	170	247	12/1/1964	180	297	6/23/1965	185	347	7/8/1986	193	397
8/18/1995	170	248	2/2/1972	180	298	10/7/2015	185	348	9/12/1989	193	398
5/23/2000	170	249	3/14/1972	180	299	3/3/1982	186	349	5/15/2012	193	399
5/11/2003	170	250	2/4/1974	180	300	8/6/1985	186	350	4/7/1982	194	400

Date	Hardness (Ca, Mg) mg/L	Sample Count	Date	Hardness (Ca, Mg) mg/L	Sample Count	Date	Hardness (Ca, Mg) mg/L	Sample Count
1/5/1983	194	401	1/20/1982	210	451	4/8/1981	232	501
8/7/1984	194	402	10/10/1985	210	452	10/13/1987	233	502
10/6/1970	195	403	9/9/1986	210	453	4/12/2010	234	503
9/16/2014	195	404	10/11/2000	210	454	10/11/1988	236	504
9/17/2014	195	405	11/28/2000	210	455	8/10/1971	240	505
8/3/1970	196	406	11/14/2005	210	456	12/1/1971	240	506
3/4/1986	196	407	11/15/2007	210	457	2/2/1972	240	507
1/13/1987	196	408	11/3/2014	210	458	8/16/1972	240	508
5/12/1987	196	409	5/6/1981	211	459	10/15/1980	240	509
5/2/2006	196	410	11/4/1981	211	460	1/19/2010	240	510
5/3/2006	196	411	10/31/1989	211	461	8/4/1970	242	511
5/3/2006	196	412	10/25/2016	211	462	8/3/1970	250	512
5/5/1982	197	413	10/4/1983	213	463	8/3/1970	250	513
3/8/1983	197	414	8/3/1970	214	464	12/1/1964	253	514
1/31/2006	197	415	7/8/1981	214	465	2/17/1965	253	515
5/3/2006	197	416	10/6/1982	214	466	11/3/1982	254	516
12/9/1986	199	417	9/4/1984	214	467	2/17/1965	255	517
5/3/2006	199	418	2/17/1965	216	468	8/5/1981	258	518
5/3/2006	199	419	11/5/1985	216	469	4/11/1972	260	519
9/2/1964	200	420	7/14/1987	217	470	11/3/1987	262	520
2/16/1965	200	421	10/24/2016	217	471	9/9/1981	263	521
12/3/1970	200	422	8/4/1970	218	472	9/2/1964	268	522
2/2/1971	200	423	10/8/1985	219	473	9/2/1964	270	523
8/31/1971	200	424	11/2/1971	220	474	6/2/1971	270	524
10/2/1974	200	425	10/2/1972	220	475	9/7/1972	270	525
10/3/1979	200	426	1/8/1980	220	476	10/15/1980	270	526
1/14/1981	200	427	10/21/1981	220	477	12/1/1964	271	527
1/14/1981	200	428	4/14/1982	220	478	10/7/1981	297	528
7/14/1981	200	429	10/19/1983	220	479	10/5/1971	300	529
10/7/1982	200	430	10/4/1984	220	480	11/30/1971	300	530
7/8/1987	200	431	11/4/2002	220	481	8/15/1972	300	531
11/28/2001	200	432	11/4/2003	220	482			
11/8/1983	202	433	12/2/1981	221	483			
11/4/1986	202	434	9/8/1987	221	484			
9/13/1988	202	435	11/28/2006	221	485			
6/13/1989	202	436	11/7/1988	223	486			
5/1/2006	202	437	10/9/1984	226	487			
5/2/2006	202	438	7/12/2010	226	488			
7/13/2016	202	439	6/10/1969	227	489			
9/3/1985	203	440	8/14/1969	227	490			
1/6/1982	204	441	5/5/2006	229	491			
6/9/1987	204	442	6/8/1972	230	492			
5/3/2006	204	443	7/12/1972	230	493			
12/1/1964	206	444	4/15/1981	230	494			
10/10/1989	206	445	10/6/1987	230	495			
5/3/2006	207	446	10/6/1988	230	496			
10/27/2015	207	447	10/9/1990	230	497			
10/28/2015	208	448	11/13/2006	230	498			
9/1/1964	210	449	6/3/1981	231	499			
1/9/1979	210	450	8/4/1970	232	500			

Table A4. Center Creek Tributary Dissolved Cadmium Data

Water Body	Sampling Organization[31]	Sample ID	Site Code	Sample Type	Date	Dissolved Cadmium (µg/L)
Tributary to Center Creek WBID 5003	USEPA-7	80986	5003/0.1	Grab	5/10/1993	5.5
	USEPA-7	80987	5003/0.1	Grab	9/8/1993	9.5
	MDNR	83128	5003/0.1	Grab	3/22/2001	20.1
	MDNR	205809	5003/0.1	Grab	4/13/2011	10.6
	MDNR	208061	5003/0.1	Grab	10/25/2011	0.34
	MDNR	220980	5003/0.1	Grab	4/11/2012	18.2
	MDNR	226480	5003/0.1	Grab	6/26/2012	9.59
	MDNR	233091	5003/0.1	Grab	10/24/2012	16
	MDNR	235654	5003/0.1	Grab	6/18/2013	18
	MDNR	236929	5003/0.1	Grab	10/17/2013	4.77
	MDNR	243100	5003/0.1	Grab	3/25/2014	17.6
	MDNR	243101	5003/0.1	Grab	5/21/2014	6.17
	MDNR	243102	5003/0.1	Grab	6/24/2014	5.45
	MDNR	251418	5003/0.1	Grab	9/9/2014	3.57
	MDNR	257001	5003/0.1	Grab	4/14/2015	7.11
Tributary to Center Creek WBID 5003	MDNR	257002	5003/0.1	Grab	6/9/2015	6.54
	MDNR	257003	5003/0.1	Grab	10/27/2015	3.61
	MDNR	257004	5003/0.1	Grab	2/3/2016	14.4
	MDNR	259557	5003/0.1	Grab	6/16/2016	10.3
	MDNR	273389	5003/0.1	Grab	10/26/2016	11.4
	MDNR	273390	5003/0.1	Grab	3/22/2017	20
	MDNR	273391	5003/0.1	Grab	6/8/2017	15.2

Table A5. Center Creek Tributary Dissolved Lead Data

Water Body	Sampling Organization	Sample ID	Site Code	Sample Type	Date	Dissolved Lead (µg/L)
Tributary to Center Creek WBID 5003	USEPA-7	80986	5003/0.1	Grab	5/10/1993	3
	USEPA-7	80987	5003/0.1	Grab	9/8/1993	1
	MDNR	83128	5003/0.1	Grab	3/22/2001	5.1
	MDNR	205809	5003/0.1	Grab	4/13/2011	1.53
	MDNR	208061	5003/0.1	Grab	10/25/2011	1.16
	MDNR	220980	5003/0.1	Grab	4/11/2012	5.79
	MDNR	226480	5003/0.1	Grab	6/26/2012	0.9
	MDNR	233091	5003/0.1	Grab	10/24/2012	6.24
	MDNR	235654	5003/0.1	Grab	6/18/2013	3
	MDNR	236929	5003/0.1	Grab	10/17/2013	0.25

[31] USEPA-7 = United State Environmental Protection Agency Region Seven

	MDNR	243100	5003/0.1	Grab	3/25/2014	2.33
	MDNR	243101	5003/0.1	Grab	5/21/2014	0.59
	MDNR	243102	5003/0.1	Grab	6/24/2014	0.81
	MDNR	251418	5003/0.1	Grab	9/9/2014	0.25
	MDNR	257001	5003/0.1	Grab	4/14/2015	0.98
	MDNR	257002	5003/0.1	Grab	6/9/2015	1.74
	MDNR	257003	5003/0.1	Grab	10/27/2015	0.25
	MDNR	257004	5003/0.1	Grab	2/3/2016	9.15
	MDNR	259557	5003/0.1	Grab	6/16/2016	8.86
	MDNR	273389	5003/0.1	Grab	10/26/2016	6.41
	MDNR	273390	5003/0.1	Grab	3/22/2017	13.8
	MDNR	273391	5003/0.1	Grab	6/8/2017	8.35

Table A6. Center Creek Tributary Dissolved Zinc Data

Water Body	Sampling Organization	Sample ID	Site Code	Sample Type	Date	Dissolved Zinc (µg/L)
Tributary to Center Creek WBID 5003	USEPA-7	80986	5003/0.1	Grab	5/10/1993	0.326
	USEPA-7	80987	5003/0.1	Grab	9/8/1993	3.87
	MDNR	83128	5003/0.1	Grab	3/22/2001	4.95
	MDNR	205809	5003/0.1	Grab	4/13/2011	3.52
	MDNR	208061	5003/0.1	Grab	10/25/2011	0.776
	MDNR	220980	5003/0.1	Grab	4/11/2012	5.61
	MDNR	226480	5003/0.1	Grab	6/26/2012	3.63
	MDNR	233091	5003/0.1	Grab	10/24/2012	3.56
	MDNR	235654	5003/0.1	Grab	6/18/2013	3.35
	MDNR	236929	5003/0.1	Grab	10/17/2013	3.86
	MDNR	243100	5003/0.1	Grab	3/25/2014	4.46
	MDNR	243101	5003/0.1	Grab	5/21/2014	4.14
	MDNR	243102	5003/0.1	Grab	6/24/2014	3.87
	MDNR	251418	5003/0.1	Grab	9/9/2014	3.5
	MDNR	257001	5003/0.1	Grab	4/14/2015	2.05
	MDNR	257002	5003/0.1	Grab	6/9/2015	1.94
	MDNR	257003	5003/0.1	Grab	10/27/2015	3.39
	MDNR	257004	5003/0.1	Grab	2/3/2016	2.55
	MDNR	259557	5003/0.1	Grab	6/16/2016	1.82
	MDNR	273389	5003/0.1	Grab	10/26/2016	2.28
	MDNR	273390	5003/0.1	Grab	3/22/2017	2.91
	MDNR	273391	5003/0.1	Grab	6/8/2017	2.93

Table A7. Tributary to Center Creek Hardness Data

Date	Hardness (Ca, Mg) mg/L	Sample Count
5/10/1993	94	1
6/16/2016	229	2
4/14/2015	239	3
6/9/2015	247	4
6/8/2017	275	5
3/22/2017	290	6
4/13/2011	293	7
3/25/2014	296	8
6/18/2013	313	9
5/21/2014	315	10
2/3/2016	317	11
6/24/2014	321	12
10/27/2015	322	13
10/17/2013	323	14
10/25/2011	334	15
9/9/2014	374	16
4/11/2012	380	17
10/26/2016	380	18
9/8/1993	386	19

Table A8. Bens Branch Sediment Cadmium Data

Water Body	Sampling Organization[32]	Sample ID	Site Code	Sample Type	Date	Sediment Cadmium (mg/kg)
Bens Brach WBID 3980	UMC	183858	3980/0.5	Grab	12/1/1991	85
	BV	228216	3980/1.4	Grab	5/3/2006	16.3
	USGS-BRD	228187	3980/0.1	Grab	8/20/2007	376

Table A9. Bens Branch Sediment Lead Data

Water Body	Sampling Organization	Sample ID	Site Code	Sample Type	Date	Sediment Lead (mg/kg)
Bens Brach WBID 3980	USGS	183679	3980/2.0	Grab	9/1/1976	400
	USGS	235211	3980/1.4	Grab	9/21/1976	400
	EE	183815	3980/0.1	Grab	2/1/1986	850
	EE	183816	3980/2.0	Grab	2/1/1986	1100
	EE	183817	3980/2.3	Grab	2/1/1986	1000
	UMC	183858	3980/0.5	Grab	12/1/1991	2271
	BV	228216	3980/1.4	Grab	5/3/2006	285
	USGS-BRD	228187	3980/0.1	Grab	8/20/2007	1050
	USGS	183679	3980/2.0	Grab	9/1/1976	400

[32] UMC = University of Missouri, Columbia

	USGS	235211	3980/1.4	Grab	9/21/1976	400
	EE	183815	3980/0.1	Grab	2/1/1986	850
	EE	183816	3980/2.0	Grab	2/1/1986	1100
	EE	183817	3980/2.3	Grab	2/1/1986	1000
	UMC	183858	3980/0.5	Grab	12/1/1991	2271
	BV	228216	3980/1.4	Grab	5/3/2006	285
	USGS-BRD	228187	3980/0.1	Grab	8/20/2007	1050

Table A10. Bens Branch Sediment Zinc Data

Water Body	Sampling Organization	Sample ID	Site Code	Sample Type	Date	Sediment Zinc (mg/kg)
Bens Brach WBID 3980	USGS	183679	3980/2.0	Grab	9/1/1976	2800
	USGS	235211	3980/1.4	Grab	9/21/1976	2800
	EE	183817	3980/2.3	Grab	2/1/1986	2600
	EE	183815	3980/0.1	Grab	2/1/1986	14000
	EE	183816	3980/2.0	Grab	2/1/1986	4700
	UMC	183858	3980/0.5	Grab	12/1/1991	24673
	BV	228216	3980/1.4	Grab	5/3/2006	2210
	USGS-BRD	228187	3980/0.1	Grab	8/20/2007	19900
	USGS	183679	3980/2.0	Grab	9/1/1976	2800
	USGS	235211	3980/1.4	Grab	9/21/1976	2800
	EE	183817	3980/2.3	Grab	2/1/1986	2600
	EE	183815	3980/0.1	Grab	2/1/1986	14000
	EE	183816	3980/2.0	Grab	2/1/1986	4700
	UMC	183858	3980/0.5	Grab	12/1/1991	24673
	BV	228216	3980/1.4	Grab	5/3/2006	2210
	USGS-BRD	228187	3980/0.1	Grab	8/20/2007	19900

Table A11. Bens Branch Dissolved Cadmium Data

Water Body	Sampling Organization	Sample ID	Site Code	Sample Type	Date	Dissolved Cadmium (µg/L)
Bens Brach WBID 3980	USGS	235184	3980/1.4	Grab	3/9/1976	25
	USGS	235186	3980/3.2	Grab	3/10/1976	27
	USGS	235185	3980/1.4	Grab	6/23/1976	74
	USEPA-7	80988	3980/0.5	Grab	5/10/1993	24
	USEPA-7	80989	3980/0.5	Grab	9/8/1993	10
	BV	228549	3980/0.1	Grab	5/2/2006	33.9
	BV	228550	3980/1.4	Grab	5/3/2006	61.2
	MDNR	205810	3980/0.5	Grab	4/13/2011	15
	MDNR	208062	3980/0.5	Grab	10/25/2011	0.87
	MDNR	220981	3980/0.5	Grab	4/11/2012	16

	MDNR	226481	3980/0.5	Grab	6/26/2012	0.51
	MDNR	233092	3980/0.5	Grab	10/24/2012	7.8
	MDNR	235683	3980/0.5	Grab	6/18/2013	13.3
	MDNR	236977	3980/0.5	Grab	10/17/2013	0.37
	MDNR	243168	3980/0.5	Grab	3/25/2014	2.53
	MDNR	243169	3980/0.5	Grab	5/21/2014	0.2
	MDNR	243170	3980/0.5	Grab	6/24/2014	0.12
	MDNR	251451	3980/0.5	Grab	9/9/2014	0.7
	MDNR	257152	3980/0.5	Grab	4/14/2015	5.09
	MDNR	257155	3980/0.5	Grab	6/9/2015	4.95
	MDNR	257156	3980/0.5	Grab	10/27/2015	0.12
	MDNR	257158	3980/0.5	Grab	2/3/2016	5.62
	MDNR	259614	3980/0.5	Grab	6/16/2016	2.52
	MDNR	273375	3980/0.5	Grab	10/26/2016	2.05
	MDNR	273376	3980/0.5	Grab	3/22/2017	1.06
	MDNR	273379	3980/0.5	Grab	6/8/2017	5.09

Table A12. Bens Branch Dissolved Zinc Data

Water Body	Sampling Organization	Sample ID	Site Code	Sample Type	Date	Dissolved Zinc (µg/L)
Bens Brach WBID 3980	USGS	235184	3980/1.4	Grab	3/9/1976	11000
	USGS	235186	3980/3.2	Grab	3/10/1976	19000
	USGS	235185	3980/1.4	Grab	6/23/1976	6000
	USEPA-7	80988	3980/0.5	Grab	5/10/1993	5140
	USEPA-7	80989	3980/0.5	Grab	9/8/1993	2150
	BV	228549	3980/0.1	Grab	5/2/2006	9230
	BV	228550	3980/1.4	Grab	5/3/2006	8900
	MDNR	205810	3980/0.5	Grab	4/13/2011	3530
	MDNR	208062	3980/0.5	Grab	10/25/2011	1250
	MDNR	220981	3980/0.5	Grab	4/11/2012	3500
	MDNR	226481	3980/0.5	Grab	6/26/2012	680
	MDNR	233092	3980/0.5	Grab	10/24/2012	2120
	MDNR	235683	3980/0.5	Grab	6/18/2013	1740
	MDNR	236977	3980/0.5	Grab	10/17/2013	766
	MDNR	243168	3980/0.5	Grab	3/25/2014	2110
	MDNR	243169	3980/0.5	Grab	5/21/2014	572
	MDNR	243170	3980/0.5	Grab	6/24/2014	577
	MDNR	251451	3980/0.5	Grab	9/9/2014	1120
	MDNR	257152	3980/0.5	Grab	4/14/2015	2380
	MDNR	257155	3980/0.5	Grab	6/9/2015	2020
	MDNR	257156	3980/0.5	Grab	10/27/2015	727
	MDNR	257158	3980/0.5	Grab	2/3/2016	2320
	MDNR	259614	3980/0.5	Grab	6/16/2016	1910
	MDNR	273375	3980/0.5	Grab	10/26/2016	1420
	MDNR	273376	3980/0.5	Grab	3/22/2017	833
	MDNR	273379	3980/0.5	Grab	6/8/2017	2370

Table A13. Bens Branch Hardness Data

Date	Hardness (Ca, Mg) mg/L	Sample Count
3/10/1976	120	1
6/23/1976	130	2
6/18/2013	290	3
3/22/2017	362	4
10/26/2016	374	5
5/21/2014	416	6
10/17/2013	419	7
10/27/2015	428	8
6/8/2017	429	9

10/25/2011	437	10
2/3/2016	449	11
6/9/2015	457	12
4/11/2012	470	13
6/16/2016	480	14
4/14/2015	488	15
6/24/2014	501	16
3/9/1976	510	17
4/13/2011	516	18
3/25/2014	524	19
9/9/2014	536	20
5/10/1993	547	21
9/8/1993	597	22
5/2/2006	683	23
5/3/2006	750	24

Appendix B: Illustrative Assessment Figures

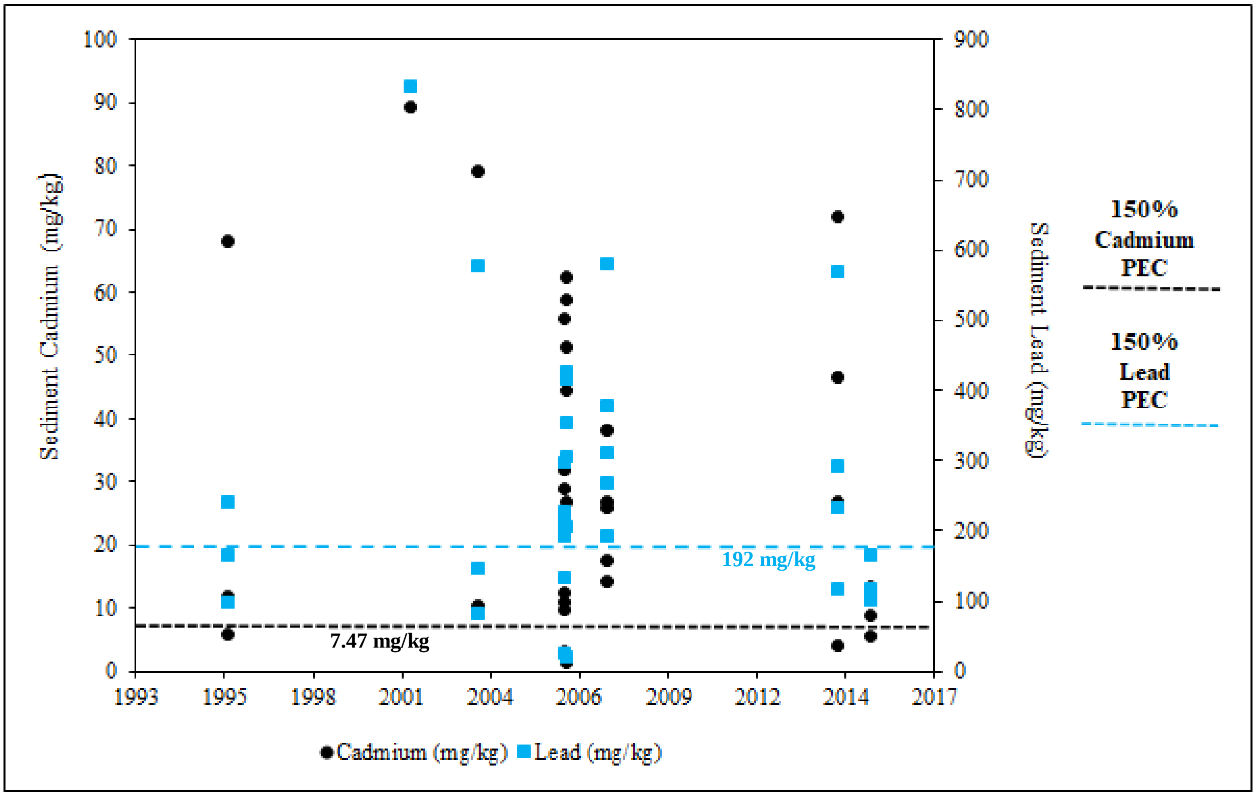

Figure B1. Assessment data for cadmium and lead in sediment - Center Creek WBID 3203.

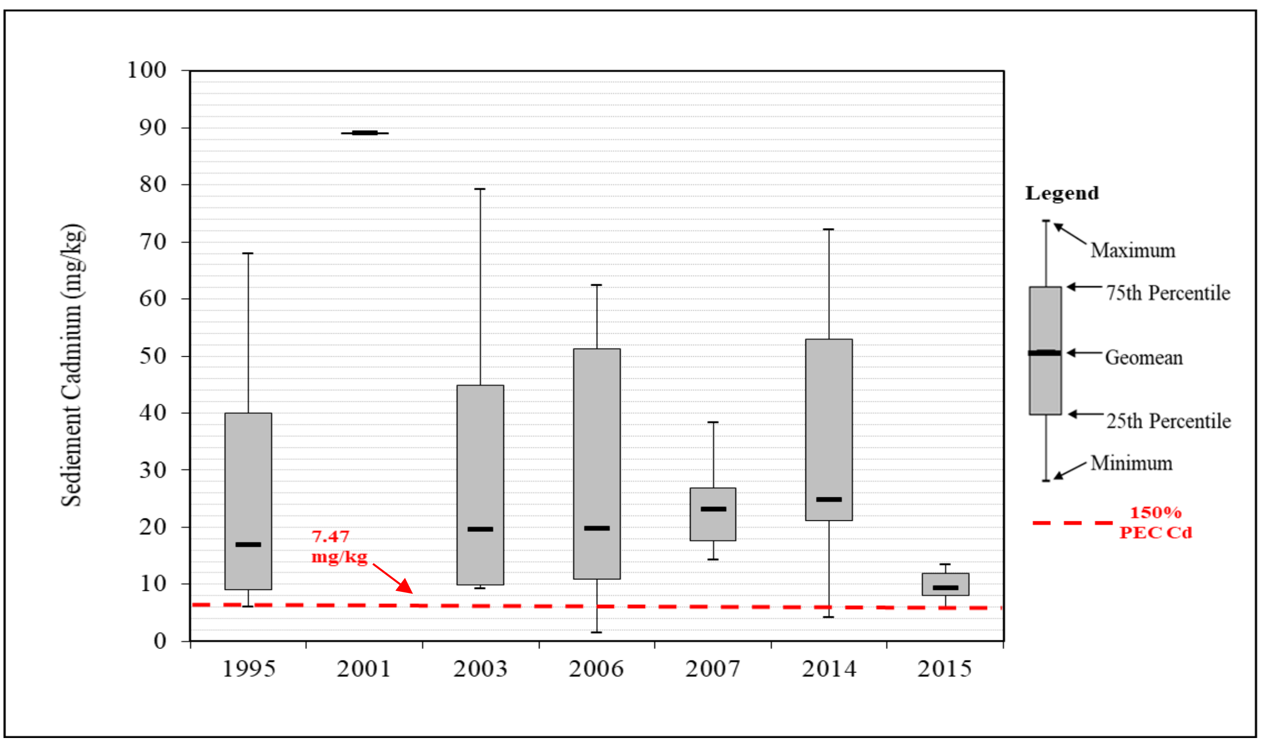

Figure B2. Box plots of assessment sediment cadmium data - Center Creek WBID 3203.

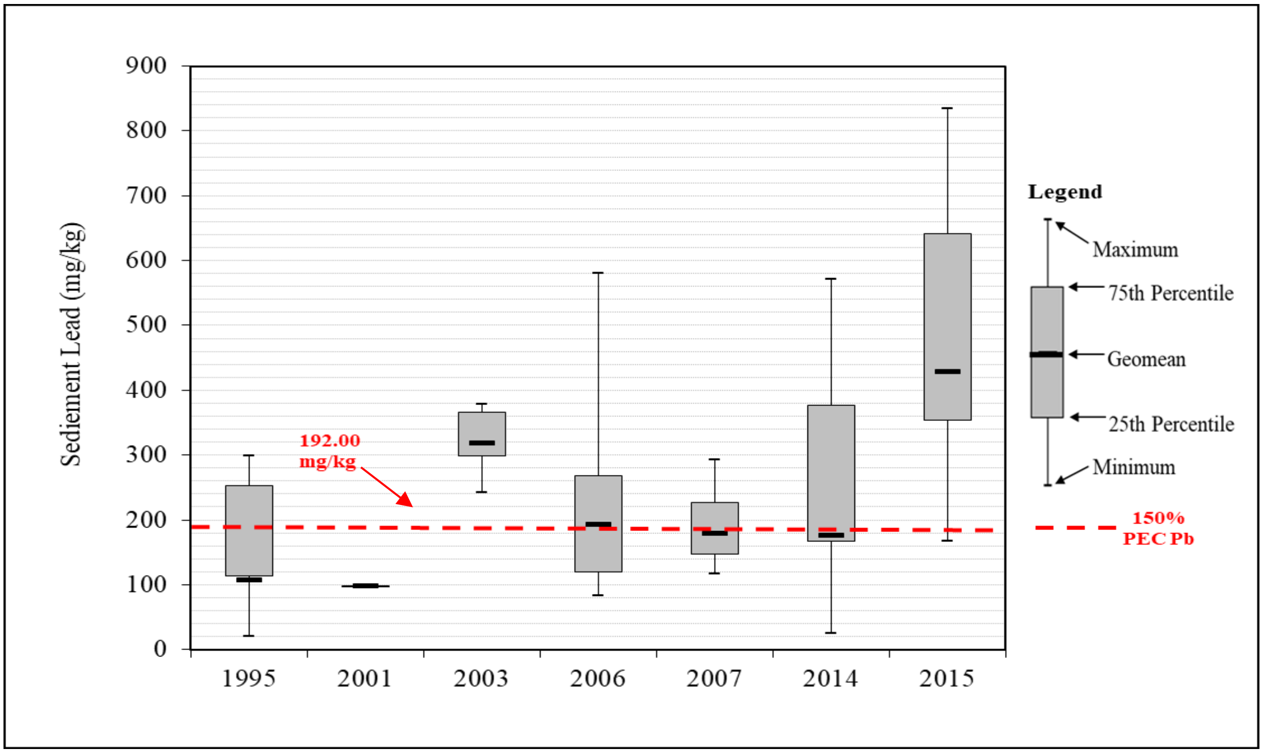

Figure B3. Box plots of assessment sediment lead data for Center Creek WBID 3203.

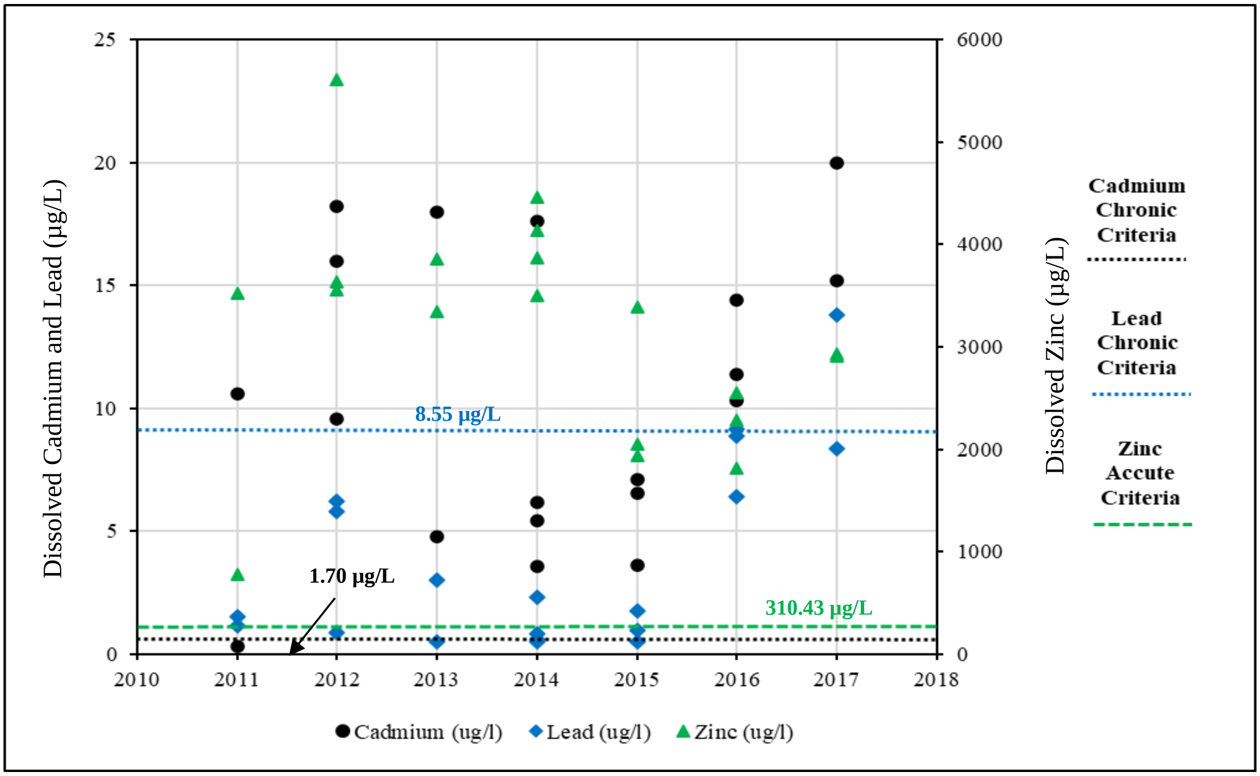

Figure B4. Assessment data for dissolved cadmium, lead, and zinc - Center Creek Tributary WBID 5003.

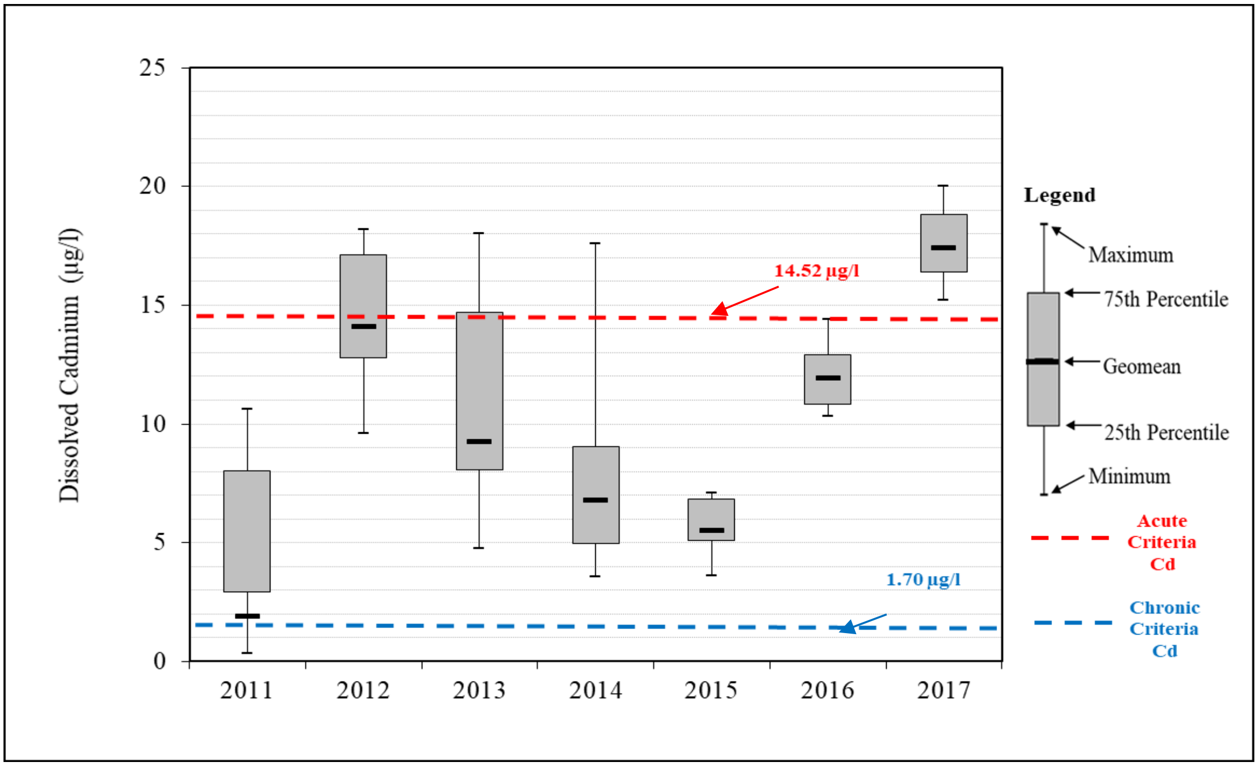

Figure B5. Box plots of cadmium assessment data - Center Creek Tributary WBID 5003.

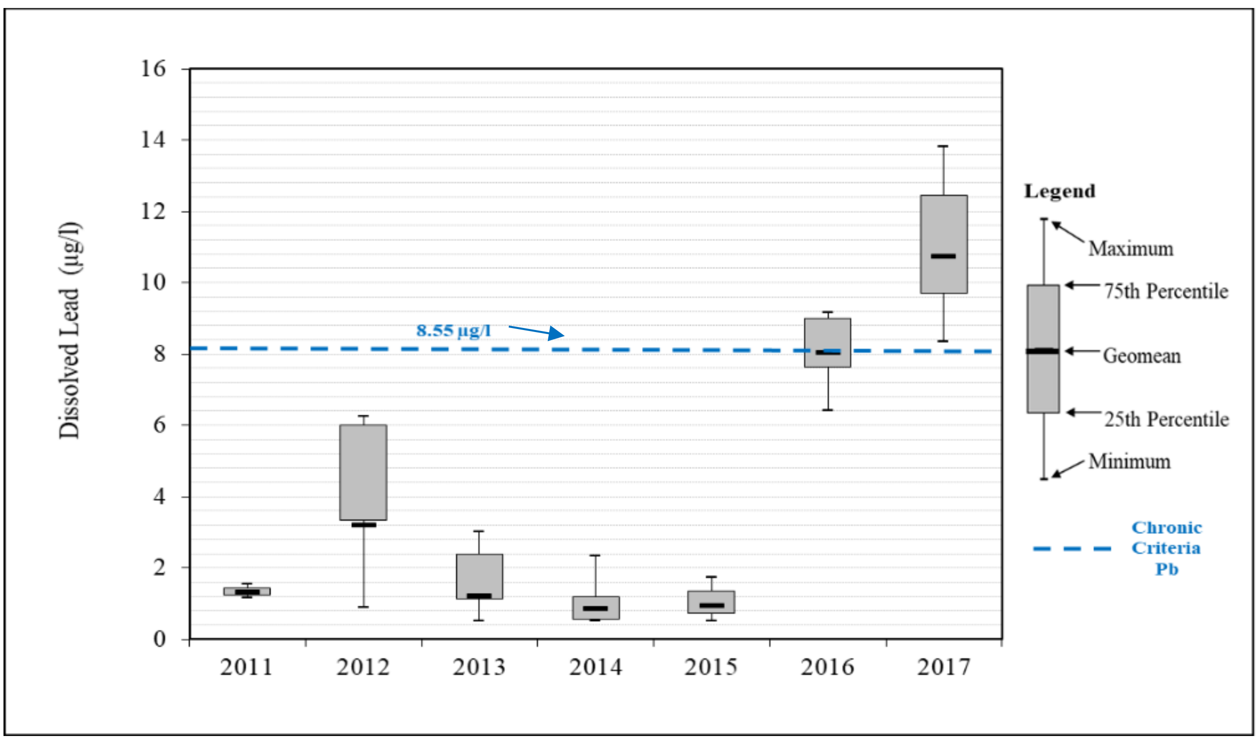

Figure B6. Box plots of assessment lead data - Center Creek Tributary WBID 5003.

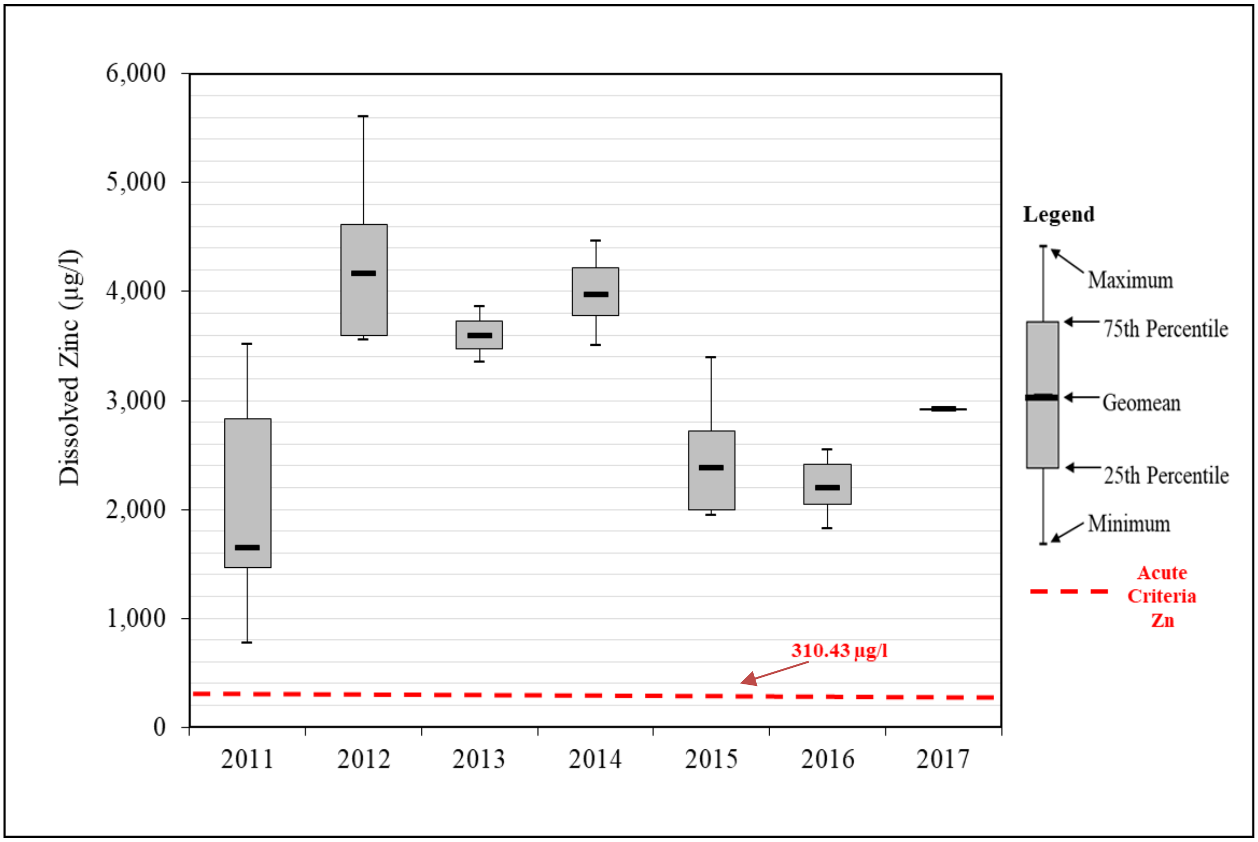

Figure B7. Box plots of assessment dissolved zinc data - Center Creek Tributary WBID 5003.

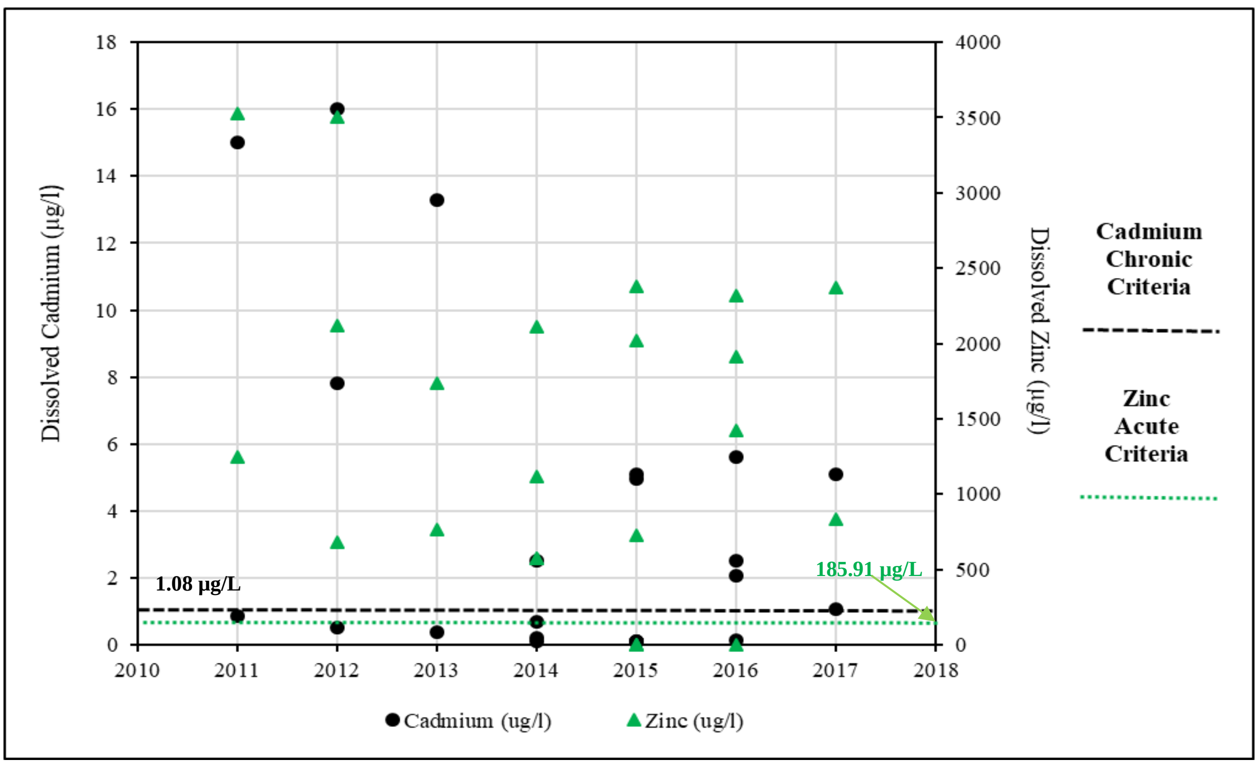

Figure B8. Assessment data for dissolved cadmium and zinc - Bens Branch WBID 3980.

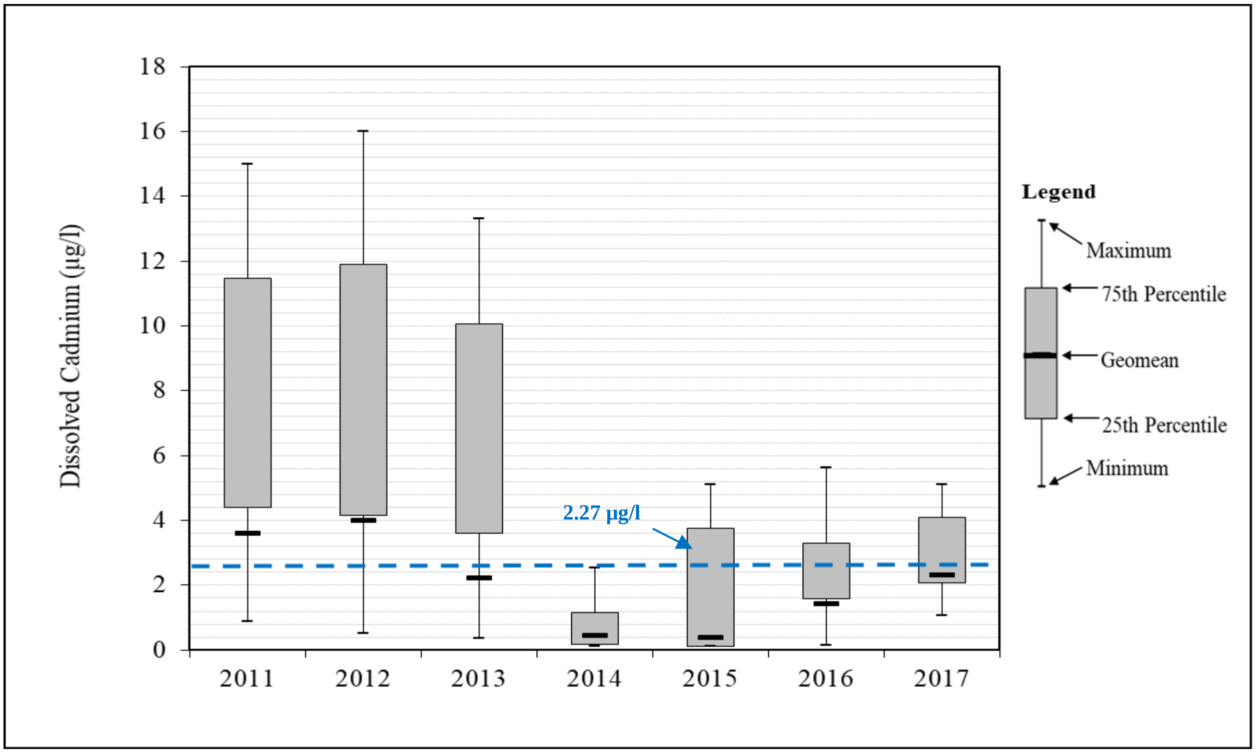

Figure B9. Box plots of assessment dissolved cadmium data - Bens Branch WBID 3980.

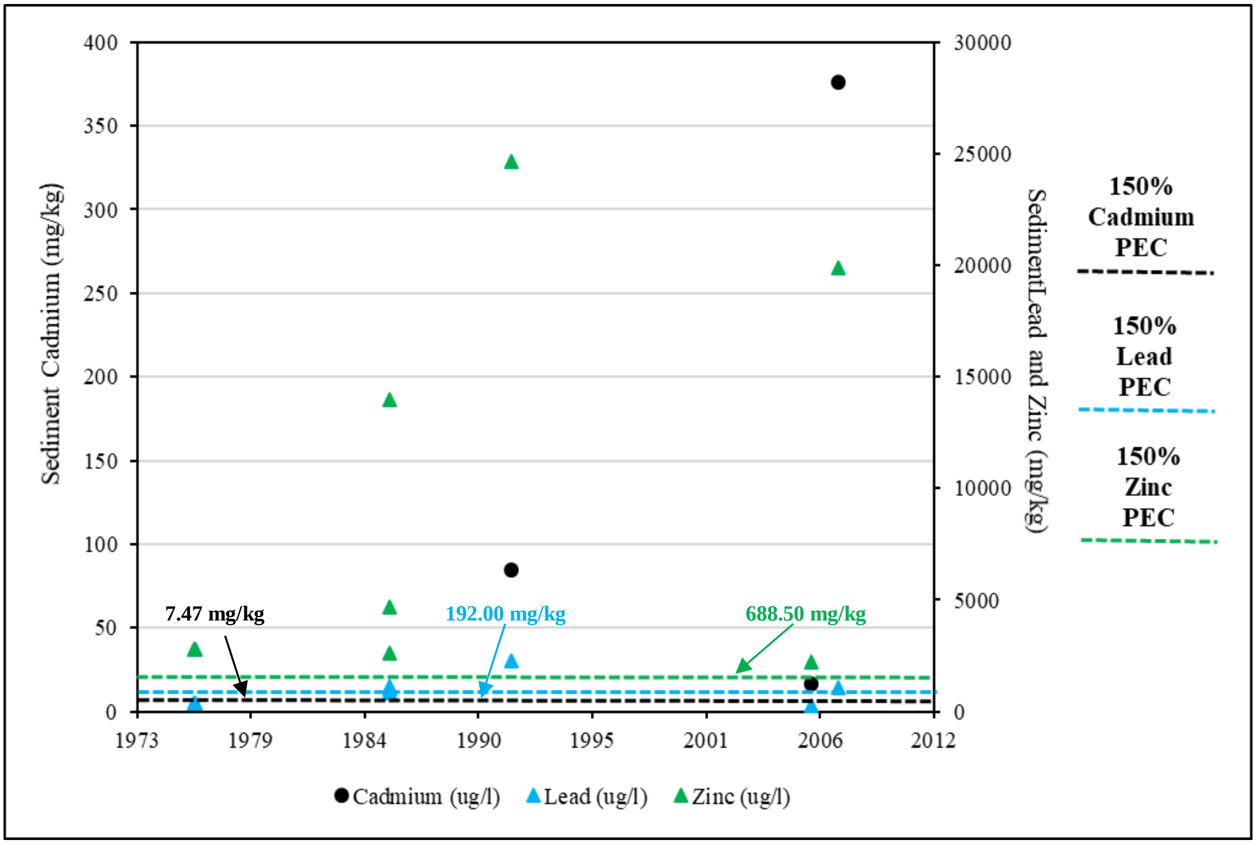

Figure B10. Assessment data sediment cadmium, lead, and zinc - Bens Branch WBID 3980.

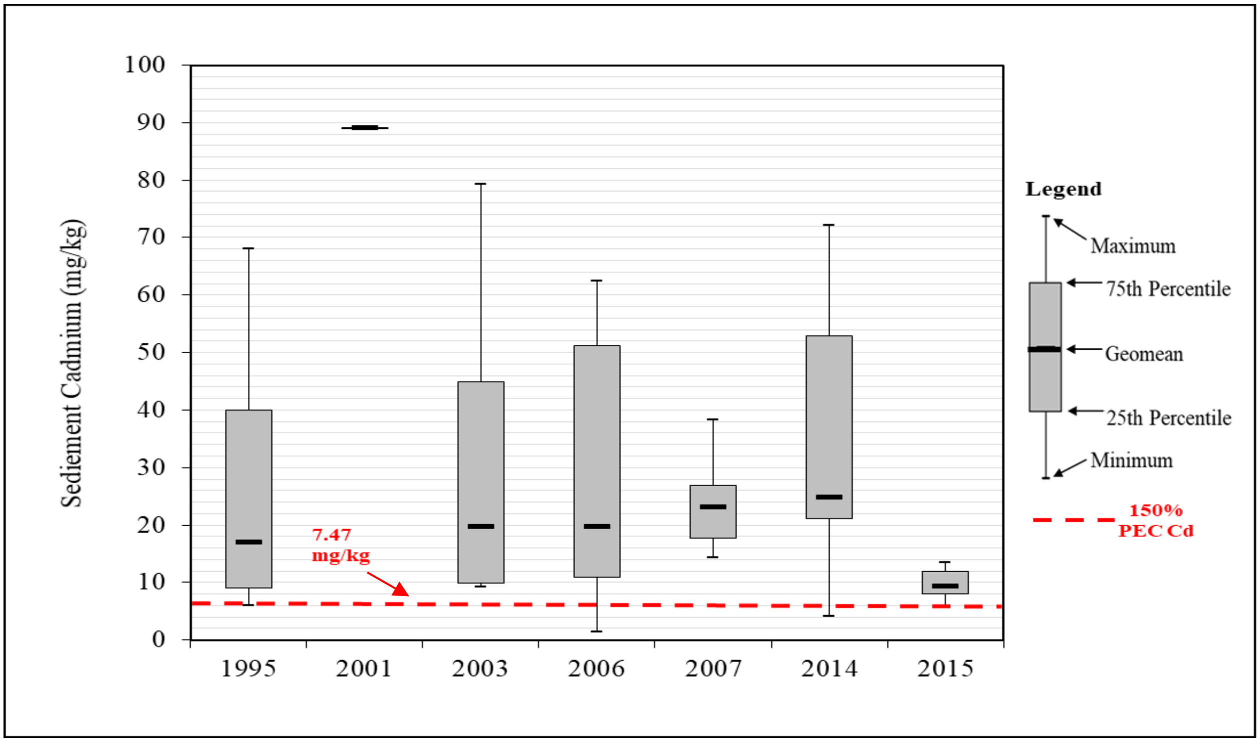

Figure B11. Box plots of assessment sediment cadmium data for Bens Branch WBID 3980.

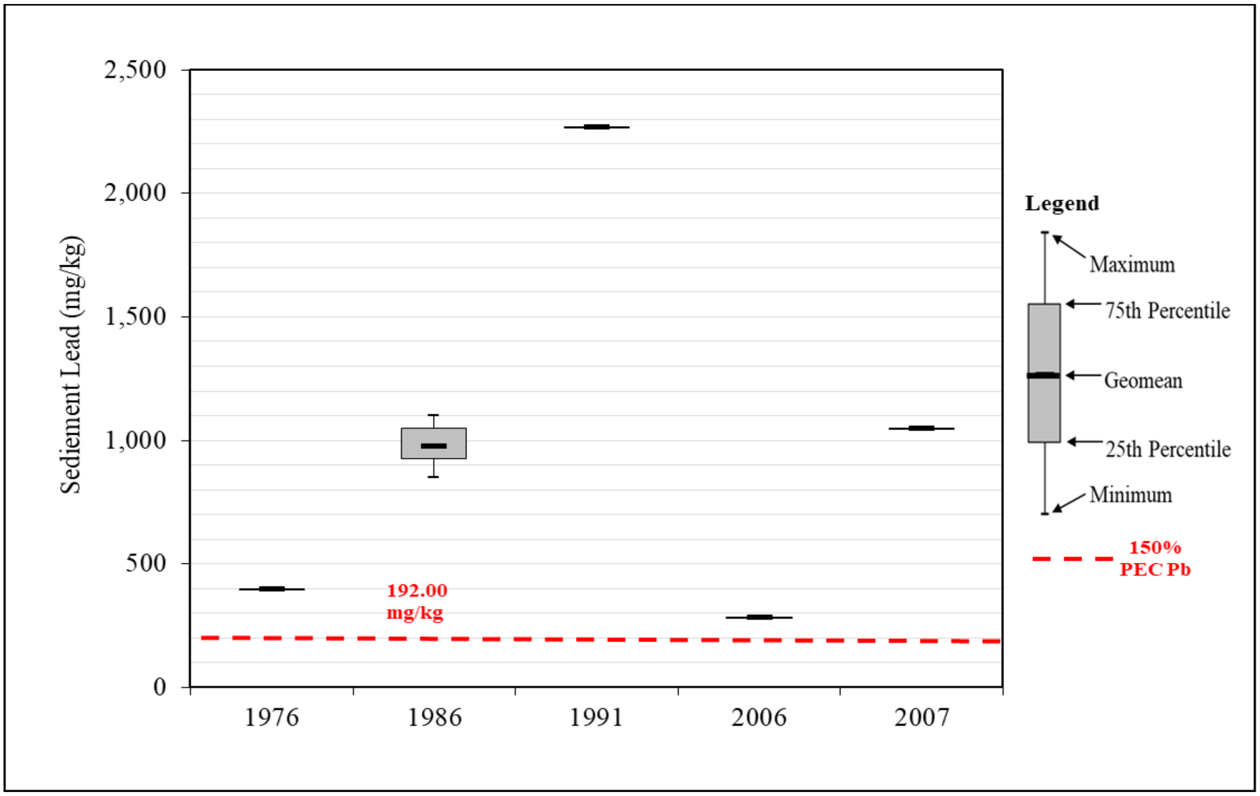

Figure B12. Box plots of assessment sediment lead data for Bens Branch WBID 3980.

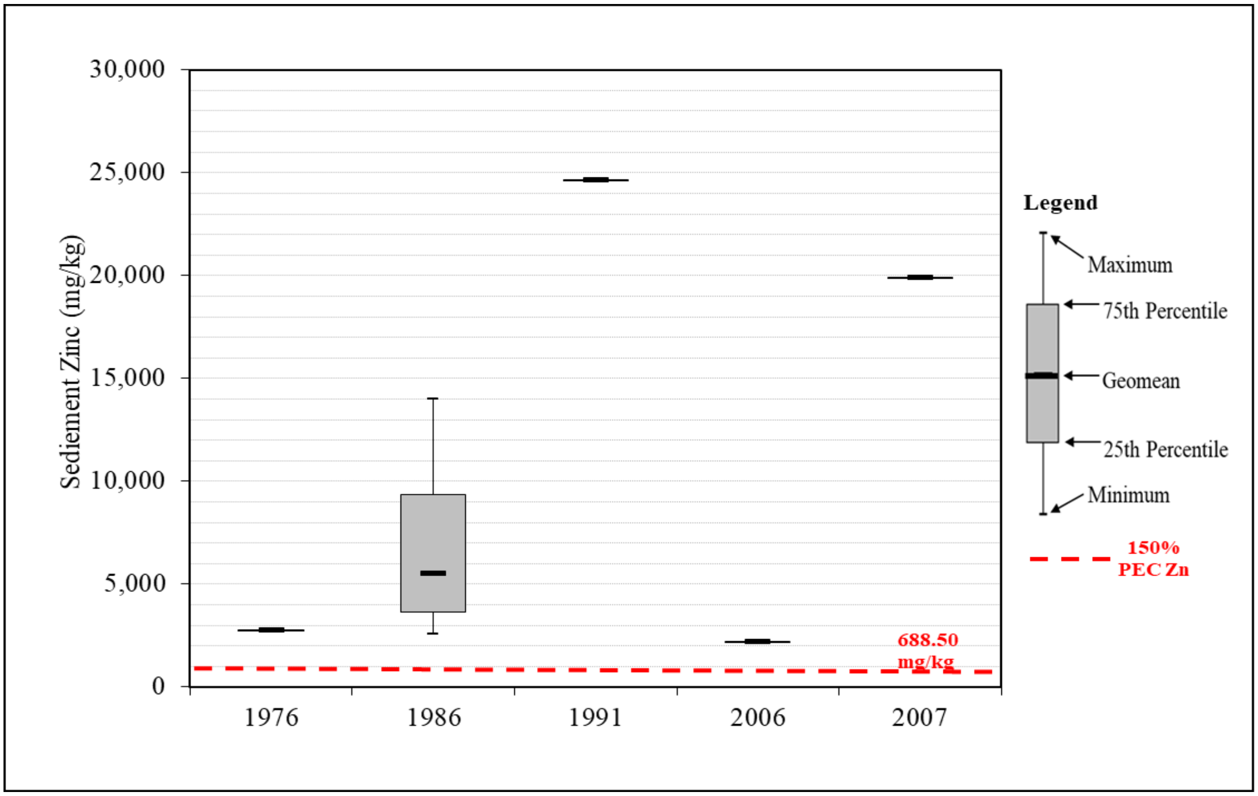

Figure B13. Box plots of assessment sediment zinc data for Bens Branch WBID 3980.

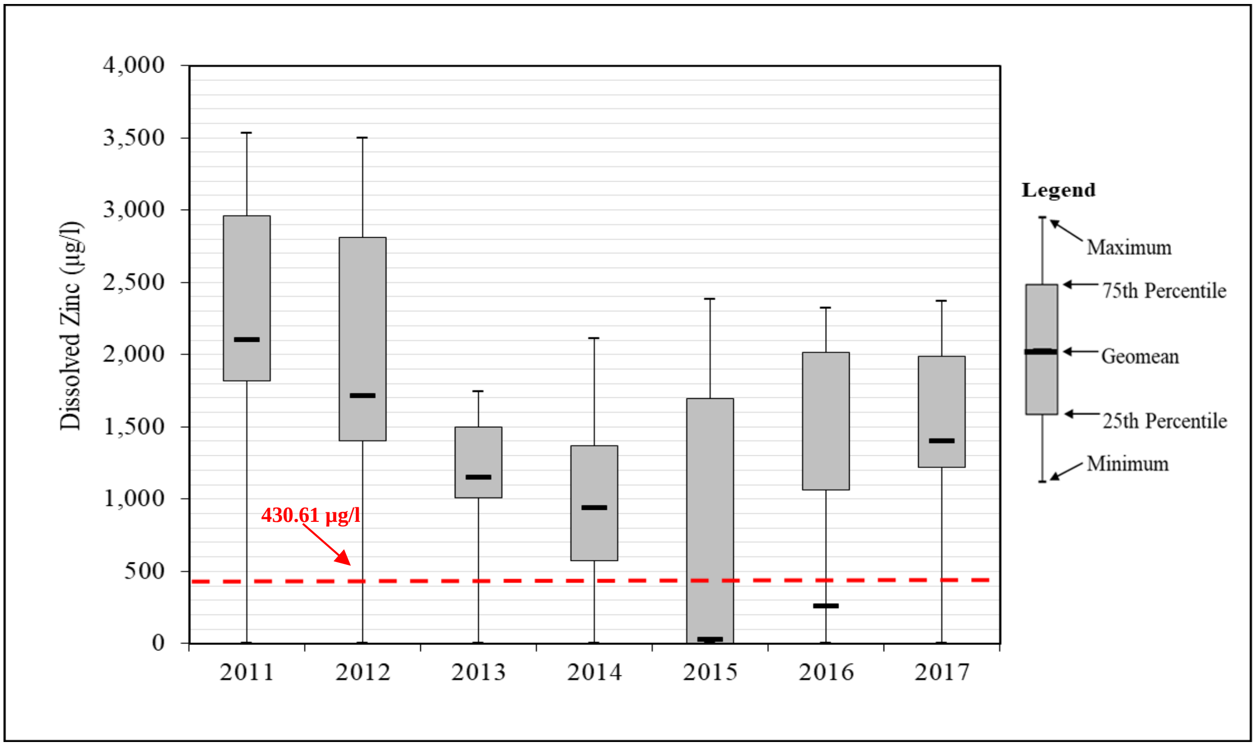

Figure B14. Box plots of assessment for dissolved zinc data - Bens Branch WBID 3980.

Appendix C: Development of Metals Load Duration Curves

Overview

The load duration curve approach was used to develop the TMDLs for the impaired water body segments in the Center Creek watershed. The load duration curve method allows for characterizing water quality concentrations (or water quality data) at different flow regimes and estimating the load allocations and wasteload allocations for each impaired segment. This method also provides a visual display of the relationship between stream flow and loading capacity. Using the duration curve framework, allowable loadings are easily presented.

Methodology

The load duration curve method requires a long-term time series of daily flows and a numeric water quality target (typically the applicable numeric criterion or a surrogate when addressing general criteria). When available, pollutant data from the impaired segment is used to provide estimates of observed loads (based on flow estimates for the same date) and are plotted along with the load duration curve to assess when the water quality target may have been exceeded. Such information is useful for determining appropriate best management practices to reduce pollutant loading.
The load duration curve method requires a long-term time series of daily flows, numeric water quality targets, and sample metals data. Metals data from the impaired segments, along with the flow estimates for the same date, are plotted along with the load duration curve to assess when the water quality target may have been exceeded.

The average daily flow data from a gage or multiple gages that are representative of the impaired reach are used to develop a load duration curve. The flow record should be of sufficient length to be able to calculate percentiles of flow. If a flow record for an impaired stream is not available, then flow data collected from a gage in a representative watershed may be used or a synthetic flow record from several gages can be developed. For the Center Creek Watershed TMDL, synthetic flow records were developed using USGS stream gages 07186400 Center Creek near Carterville, 07187000 Shoal Creek above Joplin, 07185765 Spring River at Carthage, and 06917630 East Drywood Creek at Prairie State Park. Gage data applied to develop synthetic flow ranged from September 1971 through May 2020. Nash-Sutcliffe statistics are calculated for each gage flow record in order to determine if the relationship is valid for each record (Table C1). The Nash-Sutcliffe statistic evaluates the efficiency of a predicted (modeled) flow dataset (Nash and Sutcliffe 1970). An efficiency of 1 (100 percent) describes a perfect match, while values less than zero indicate a poor fit of modeled and observed datasets (USGS 2010). This relationship must be valid in order to use the synthesized flow methodology. Model estimates are considered satisfactory if Nash-Sutcliffe statistics are greater than 50 percent (USGS 2013). Synthetic flow data values were corrected based on the proportion of the area draining to the impaired streams' watersheds (Table C2). Figures B1 through B4 present the flow duration curves for individual gage flows and curves developed for the impaired segments in the Center Creek watershed. These flows, in units of cubic feet per second, are then multiplied by the applicable water quality target (hardness dependent criteria) and a conversion factor of 5.395 in order to generate the allowable load in units of

pounds/day.[33] Despite the varying load, the targeted concentration is constant at all flow percentiles and reflects the static nature of the water quality standards.

Table C1. Nash-Sutcliffe statistics for stream gages used to develop synthetic flows.

Nash-Sutcliffe Calculations for log(cfs/mi^2)

$$E = 1 - \frac{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q_o}\right)^2}$$

				drainage area (mi^2)
#	USGS 07186400 Center Creek near Cart	1.866483	Numerator	232
		1783.797	Denominator	
		100%	Nash Sutcliffe E	
#	USGS 07187000 Shoal Creek above Jopl	1.222464	Numerator	427
		1762.107	Denominator	
		100%	Nash Sutcliffe E	
#	USGS 07185765 Spring River at Carthag	137.6864	Numerator	425
		2842.78	Denominator	
		95%	Nash Sutcliffe E	
#	USGS 06917630 East Drywood Creek at	5015	Numerator	3.38
		12204.2	Denominator	
		59%	Nash Sutcliffe E	
Mean Nash-Sutcliffe Statistic		***89%***		

Table C2. Information used for developing area corrected flow records

USGS Gage Number	Drainage Area (mi^2)
07186400	232
07187000	427
07185765	425
06917630	3.38

[33] $Load\left(\frac{\text{pounds}}{\text{day}}\right) = \left[Target\left(\frac{\mu g}{L}\right)\right] * \left[Flow\left(\frac{feet^3}{s}\right)\right] * [Conversion\ Factor]$

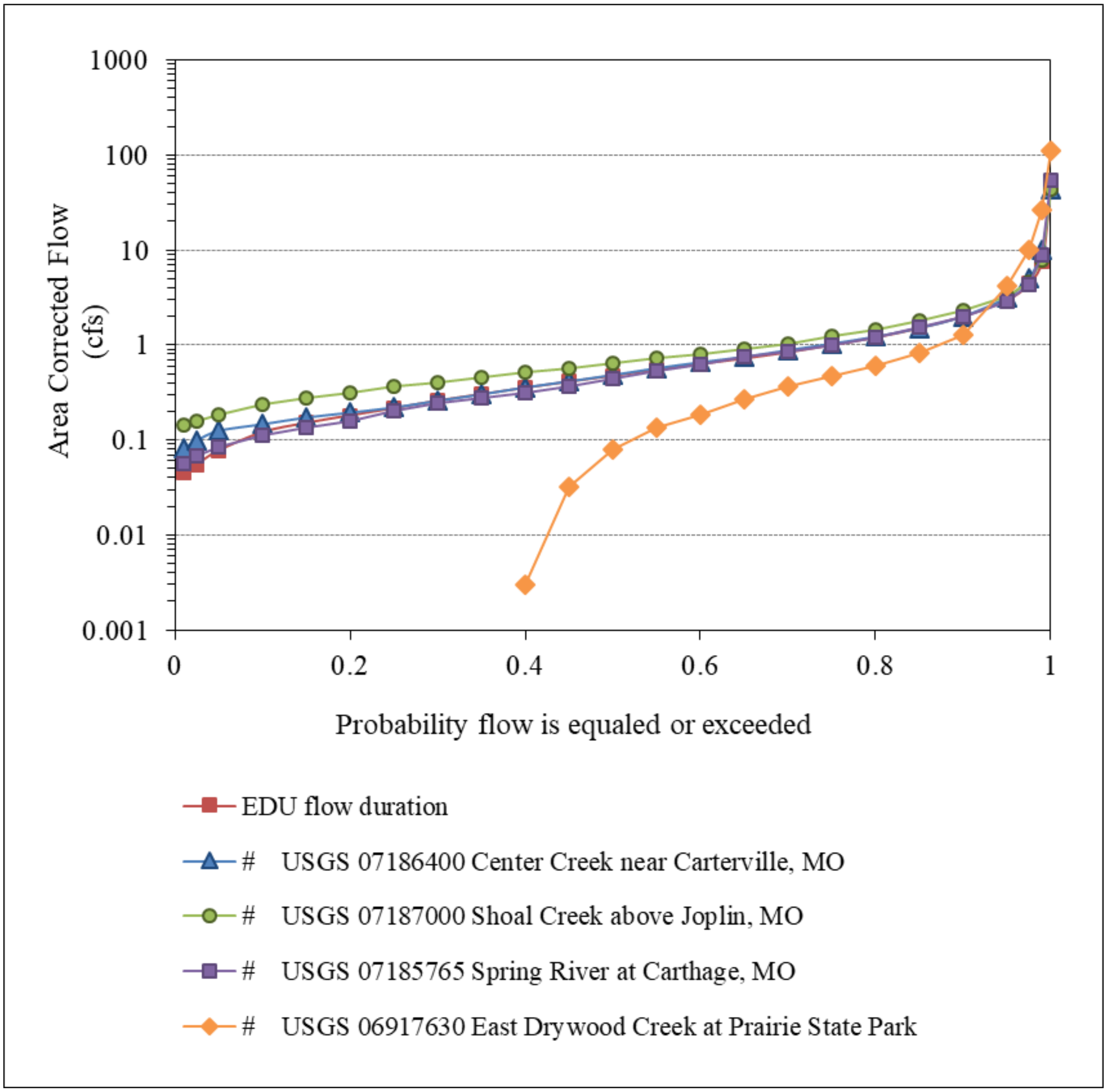

Figure C1. Synthetic flow duration used for TMDL development

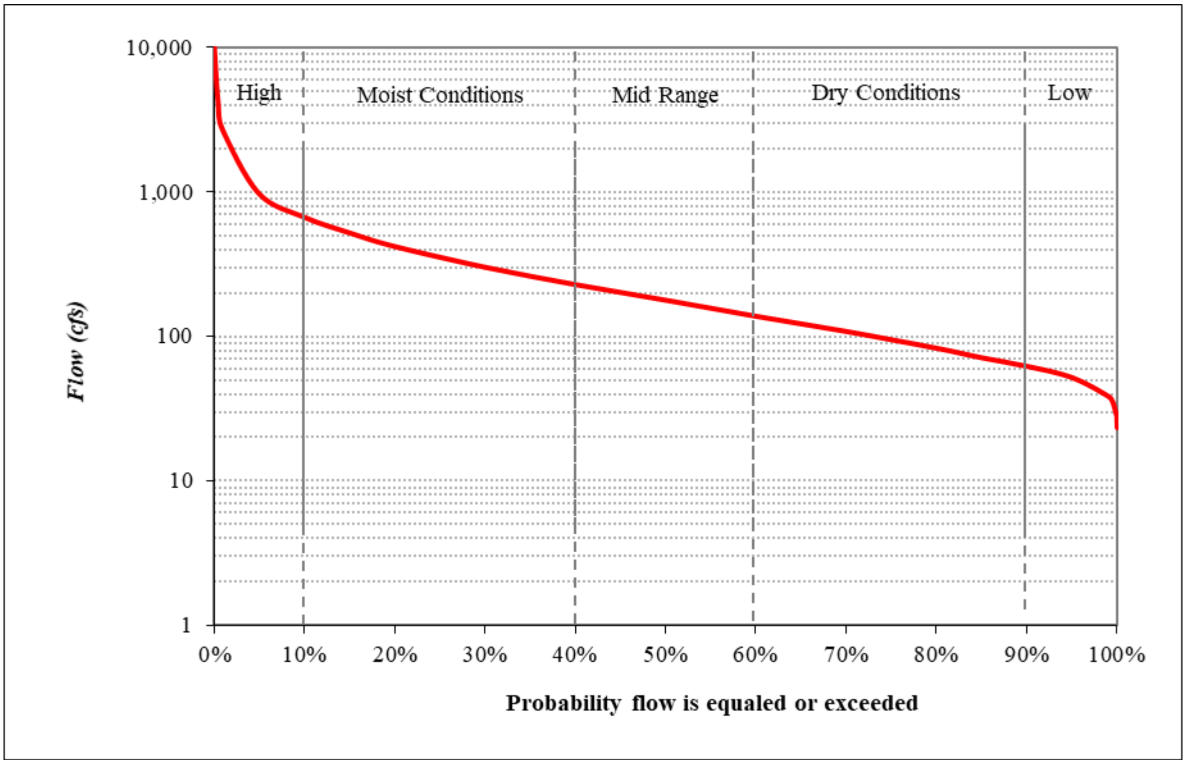

Figure C2. Center Creek, WBID 3203, flow duration curve.

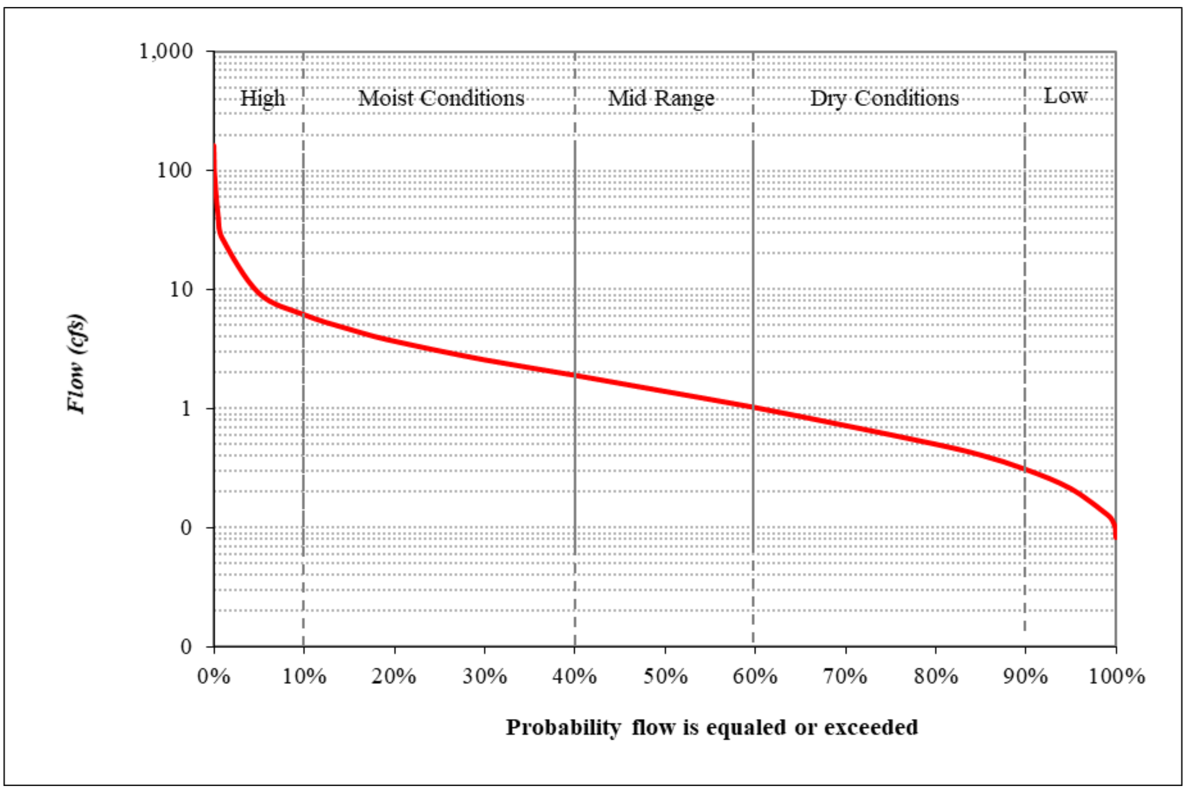

Figure C3. Tributary to Center, WBID 5003, flow duration curve.

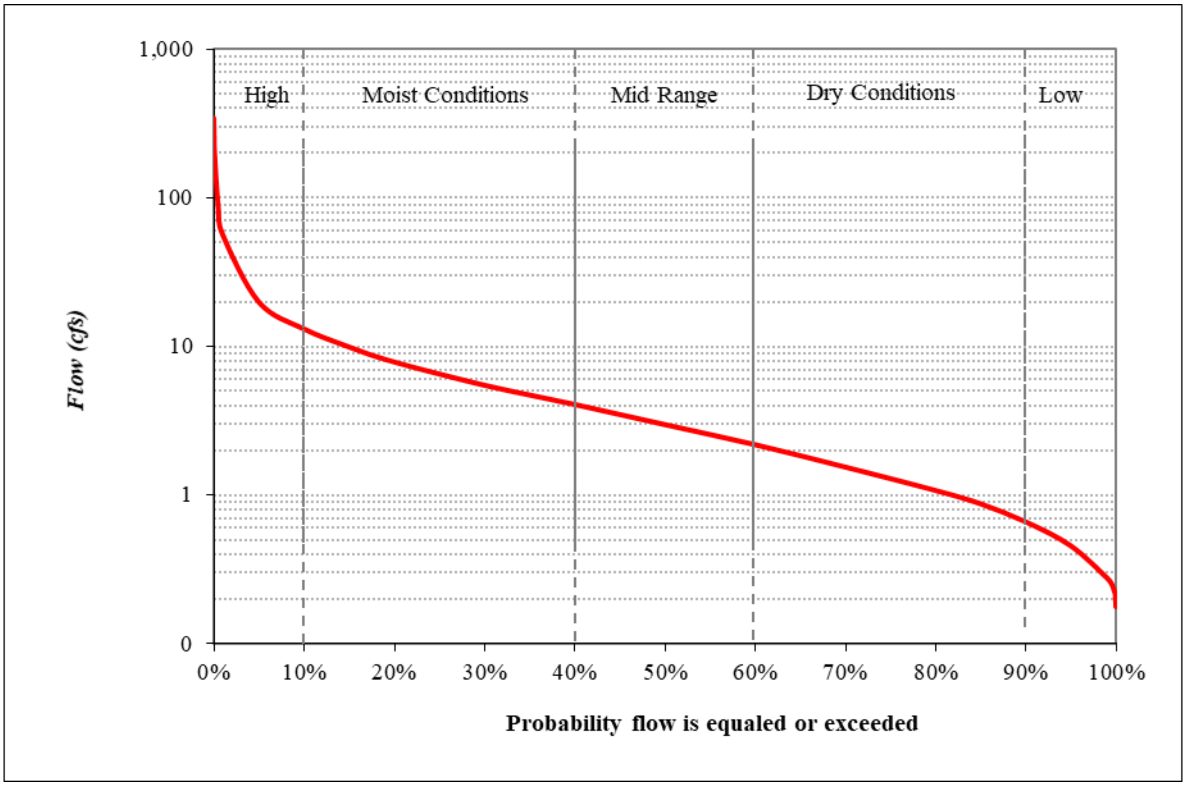

Figure C4. Bens Branch, WBID 5003, flow duration curve.